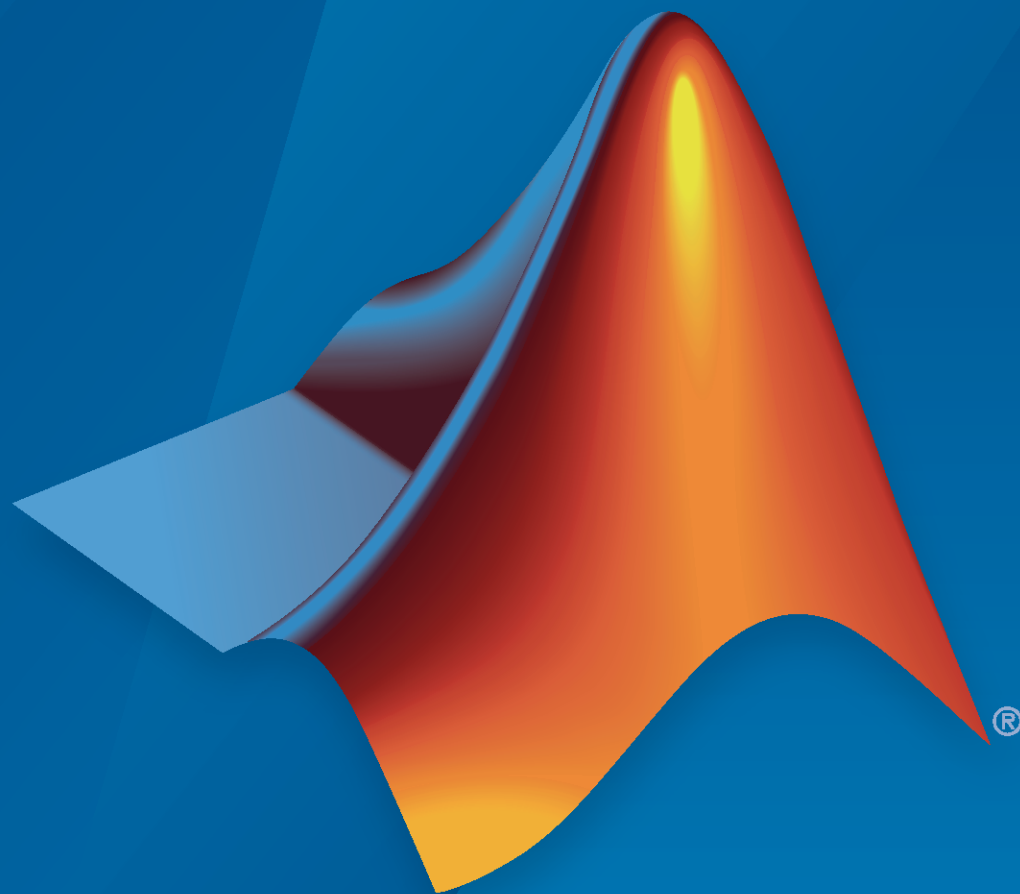


**Simscape™ Fluids™**

Reference



**MATLAB® & SIMULINK®**

R2022b



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## Revision History

March 2006	Online only	New for Version 1.0 (Release 2006a+)
September 2006	Online only	Revised for Version 1.1 (Release 2006b)
March 2007	Online only	Revised for Version 1.2 (Release 2007a)
September 2007	Online only	Revised for Version 1.2.1 (Release 2007b)
March 2008	Online only	Revised for Version 1.3 (Release 2008a)
October 2008	Online only	Revised for Version 1.4 (Release 2008b)
March 2009	Online only	Revised for Version 1.5 (Release 2009a)
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April 2011	Online only	Revised for Version 1.9 (Release 2011a)
September 2011	Online only	Revised for Version 1.10 (Release 2011b)
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September 2013	Online only	Revised for Version 1.13 (Release 2013b)
March 2014	Online only	Revised for Version 1.14 (Release 2014a)
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March 2016	Online only	Revised for Version 2.0 (Release 2016a) (Renamed from <i>SimHydraulics</i> <sup>®</sup> <i>Reference</i> )
September 2016	Online only	Revised for Version 2.1 (Release R2016b)
March 2017	Online only	Revised for Version 2.2 (Release R2017a)
September 2017	Online only	Revised for Version 2.3 (Release R2017b)
March 2018	Online only	Revised for Version 2.4 (Release R2018a)
September 2018	Online only	Revised for Version 2.5 (Release R2018b)
March 2019	Online only	Revised for Version 2.6 (Release R2019a)
September 2019	Online only	Revised for Version 2.7 (Release R2019b)
March 2020	Online only	Revised for Version 3.0 (Release R2020a)
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March 2021	Online only	Revised for Version 3.2 (Release R2021a)
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March 2022	Online only	Revised for Version 3.4 (Release R2022a)
September 2022	Online only	Revised for Version 3.5 (Release R2022b)



**1** | Blocks

**A** | Bibliography



# Blocks

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## 2-Position Valve Actuator

Actuator for two-position valves



### Library

Valve Actuators

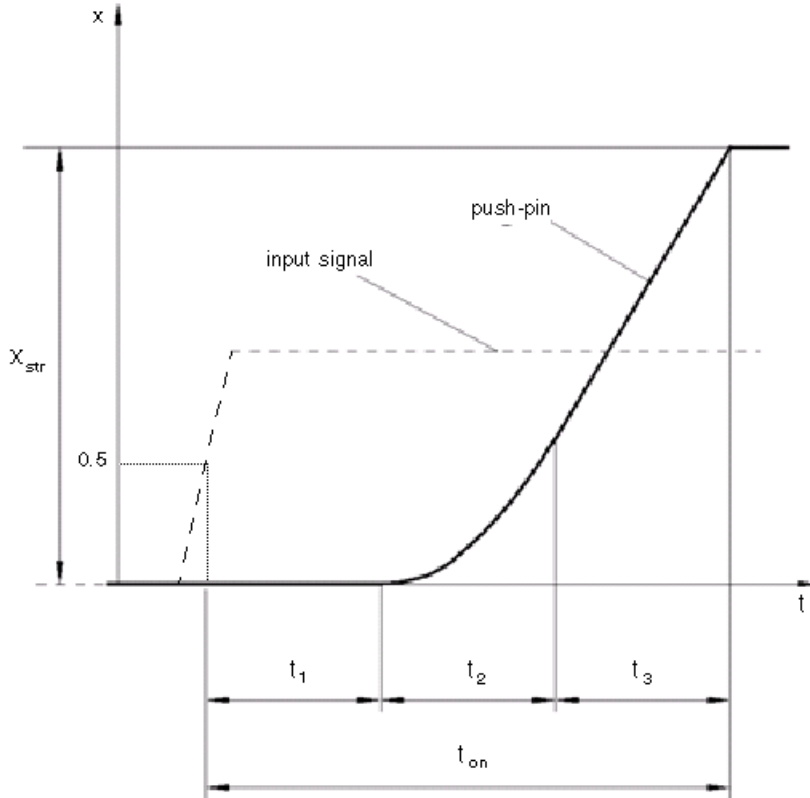
### Description

The 2-Position Valve Actuator block represents an actuator that you can use with directional valves to control their position. This actuator can drive a two-position valve. The block is developed as a data-sheet-based model and all its parameters are generally provided in catalogs or data sheets. The key parameters are the stroke, switch-on, and switch-off times.

The block accepts a physical input signal and produces a physical output signal that can be associated with a mechanical translational or rotational push-pin motion. Connect the block output to the directional valve control port.

The actuator is represented as an ideal transducer, where output does not depend on the load exerted on the push-pin and the push-pin motion profile remains the same under any loading conditions. The motion profile represents a typical transition curve for electromagnetic actuators and is shown in the following figure:





The push-pin is actuated when the input signal value crosses the threshold of 50% of the nominal input signal, where **Nominal signal value** is a block parameter. The motion is divided into three phases, equal in time: delay ( $t_1$ ), motion at constant acceleration ( $t_2$ ), and motion at constant velocity ( $t_3$ ). The motion stops when the switch-on time ( $t_{on}$ ) elapses. At this moment, the push-pin reaches the specified stroke value ( $x_{str}$ ). To return the push-pin into initial position, the control signal must cross back through the threshold of 50% of the nominal input signal, which causes the push-pin to retract. The retract motion follows exactly the same profile but “stretches” over the switch-off time. **Switching-on time** and **Switching-off time** are the block parameters.

The transition in any direction can be interrupted at any time by changing the input signal. If motion is interrupted, the switch-on or switch-off times are proportionally decreased depending on the instantaneous push-pin position.

The push-pin is actuated only by positive signal, similar to the AC or DC electromagnets. The direction of push-pin motion is controlled by the **Actuator orientation** parameter, which can have one of two values: **Acts in positive direction** or **Acts in negative direction**.

## Basic Assumptions and Limitations

Push-pin loading, such as inertia, spring, hydraulic forces, and so on, is not taken into account.

## Parameters

### Push-pin stroke

The push-pin stroke. The default value is 0.01 m.

**Switching-on time**

Time necessary to fully extend the push-pin after the control signal is applied. The default value is 0.1 s.

**Switching-off time**

Time necessary to retract push-pin from fully extended position after the input signal is removed. The default value is 0.1 s.

**Nominal signal value**

Sets the value of the nominal input signal. The output motion is initiated as the input signal crosses 50% value of the nominal signal. Other than that, the input signal has no effect on the motion profile. This parameter is meant to reproduce the rated voltage feature of an electromagnet. The default value is 24.

**Initial position**

Specifies the initial position of the push-pin. The parameter can have one of two values: `Extended` or `Retracted`. The default value is `Retracted`.

In selecting the initial position, consider the following:

- The steady-state push-pin position always corresponds to the control signal. In other words, zero or negative signal keeps the push-pin at `Retracted`, and positive signal — at `Extended`.
- At the start of simulation, if there is a discrepancy between the initial position of the push-pin, as specified by the **Initial position** parameter, and the control signal, the push-pin immediately starts moving towards the steady-state position designated by the control signal.

**Actuator orientation**

Parameter controls the direction of the push-pin motion and can have one of two values: `Acts in positive direction` or `Acts in negative direction`. The first value causes the push-pin to move in positive direction, similarly to the action of electromagnet A attached to a directional valve. If the parameter is set to `Acts in negative direction`, the control signal causes the push-pin to move in negative direction from the initial position. The default value is `Acts in positive direction`.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Initial position**
- **Actuator orientation**

All other block parameters are available for modification.

**Ports**

The block has one physical signal input port, associated with the input signal, and one physical signal output port, associated with the output signal (push-pin displacement).

**Examples**

In the “2-Position Valve Actuator” example, the hydraulic circuit contains two actuators. The first one is set to start from the retracted position, while the second one starts from the extended position.

Both actuators are driven with a Pulse Generator. The actuators start extending at 1 s, but the second actuator first retracts from 0.01 m to zero, since it was initially extended and there was no signal keeping it there.

In the “Single-Acting Cylinder with 3-Way Valve” example, the 2-Position Valve Actuator block is used along with a 3-Way Directional Valve block to simulate an electrically operated 3-way directional valve.

## **Version History**

**Introduced in R2006a**

## **Extended Capabilities**

### **C/C++ Code Generation**

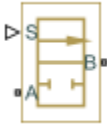
Generate C and C++ code using Simulink® Coder™.

## **See Also**

3-Position Valve Actuator | Hydraulic Double-Acting Valve Actuator | Hydraulic Single-Acting Valve Actuator | Proportional and Servo-Valve Actuator

## 2-Way Directional Valve

Hydraulic continuous 2-way directional valve



### Library

Directional Valves

### Description

The 2-Way Directional Valve block represents a continuous, 2-way directional valve, also referred to as a shut-off valve. It is the device that controls the connection between two lines. The block has two hydraulic connections, corresponding to inlet port (A) and outlet port (B), and one physical signal port connection (S), which controls the spool position. The block is built based on a Variable Orifice block, where the **Orifice orientation** parameter is set to **Opens in positive direction**. This means that positive signal  $x$  at port S opens the orifice, and its instantaneous opening  $h$  is computed as follows:

$$h = x_0 + x$$

where

$h$	Orifice opening
$x_0$	Initial opening
$x$	Control member displacement from initial position

Because the block is based on a variable orifice, you can choose one of the following model parameterization options:

- By **maximum area and opening** — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.
- By **area vs. opening table** — Use this option if the catalog or data sheet provides a table of the orifice passage area based on the control member displacement  $A=A(h)$ .
- By **pressure-flow characteristic** — Use this option if the catalog or data sheet provides a two-dimensional table of the pressure-flow characteristics  $q=q(p, h)$ .

In the first case, the passage area is assumed to be linearly dependent on the control member displacement, that is, the orifice is assumed to be closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. In the second case, the passage area is determined by one-dimensional interpolation from the table  $A=A(h)$ . Flow rate is determined analytically, which additionally requires data such as flow discharge coefficient, critical Reynolds number, and fluid density and viscosity. The computation accounts for the laminar and turbulent flow regimes by monitoring the Reynolds number and comparing its value

with the critical Reynolds number. See the Variable Orifice block reference page for details. In both cases, a small leakage area is assumed to exist even after the orifice is completely closed. Physically, it represents a possible clearance in the closed valve, but the main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause simulation to fail.

In the third case, when an orifice is defined by its pressure-flow characteristics, the flow rate is determined by two-dimensional interpolation. In this case, neither flow regime nor leakage flow rate is taken into account, because these features are assumed to be introduced through the tabulated data. Pressure-flow characteristics are specified with three data sets: array of orifice openings, array of pressure differentials across the orifice, and matrix of flow rate values. Each value of a flow rate corresponds to a specific combination of an opening and pressure differential. In other words, characteristics must be presented as the Cartesian mesh, i.e., the function values must be specified at vertices of a rectangular array. The argument arrays (openings and pressure differentials) must be strictly increasing. The vertices can be nonuniformly spaced. You have a choice of three interpolation methods and two extrapolation methods.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $p = p_A - p_B$ . Positive signal at the physical signal port S opens the valve.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- Spool loading, such as inertia, spring, hydraulic forces, and so on, is not taken into account.

## Parameters

### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

**Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3$  m. This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

**Tabulated valve openings**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

**Tabulated valve passage area**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $m^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

**Tabulated pressure differentials**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

**Tabulated flow rates**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $m^3/s$ , are:

```
[ -1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
  -2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
  -0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
  -0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
  -0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

**Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (**By area vs. opening table**) or surface (**By pressure-flow characteristic**) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Initial opening

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The default value is 0.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Interpolation method**
- **Extrapolation method**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

S

Physical signal port to control spool displacement.

## Examples

In the “Closed-Loop Actuator with 2-Way Valve” example, the 2-Way Directional Valve block is used to control the position of a double-acting cylinder. At the start of simulation, the valve is open by 0.42 mm to make the circuit initial position as close as possible to its neutral position.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

3-Way Directional Valve | 4-Way Directional Valve



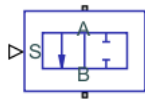
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 2-Way Directional Valve (IL)

2-way flow control valve in isothermal systems

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



### Description

The 2-Way Directional Valve (IL) block represents a two-way valve, such as a shut-off valve. Use this block to simulate a flow-reducing control element that responds to pressures in another part of the system.

The block uses a variable orifice to control the flow between ports **A** and **B**. The physical signal at port **S** triggers the spool motion to open or shut the valve. For more details about how the block calculates flow rate through a variable orifice, see Orifice (IL).

### Orifice Parameterizations

You can parameterize the valve opening linearly or by using tabulated data.

#### Linear

When you set **Orifice parameterization** to Linear - Area vs. spool travel, the opening area is a linear function of the spool travel distance.

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where

- $A_{orifice}$  is the opening area.
- $\Delta S$  is the spool travel distance input at port **S**.  $\Delta S = S - S_{max} + \Delta S_{max}$ .
- $\Delta S_{max}$  is the value of the **Spool travel between closed and open orifice** parameter.
- $A_{Leak}$  is the value of the **Leakage area** parameter.
- $A_{max}$  is the value of the **Maximum orifice area** parameter.

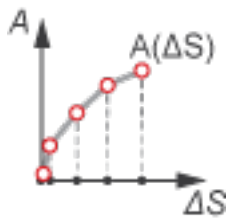
Note the linear scaling from  $A_{Leak}$  to  $A_{max}$  in the figure.



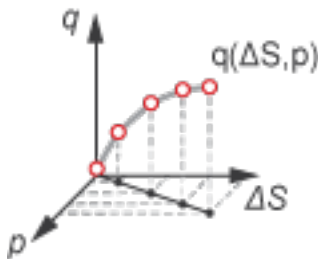
When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

### Tabulated

When you set **Orifice parameterization** to Tabulated data - Area vs. spool travel, the block uses the **Spool travel vector** and **Orifice area vector** parameters to define the relationship between  $A_{orifice}$  and  $\Delta S$  by interpolation.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Orifice area vector** parameter, respectively.



When you set **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop, the block uses the **Volumetric flow rate table,  $q(ds,dp)$** , **Pressure drop vector,  $dp$** , and **Spool travel vector,  $ds$**  parameters to define the volumetric flow rate,  $q(\Delta S, p)$ .



### Visualize Orifice Openings

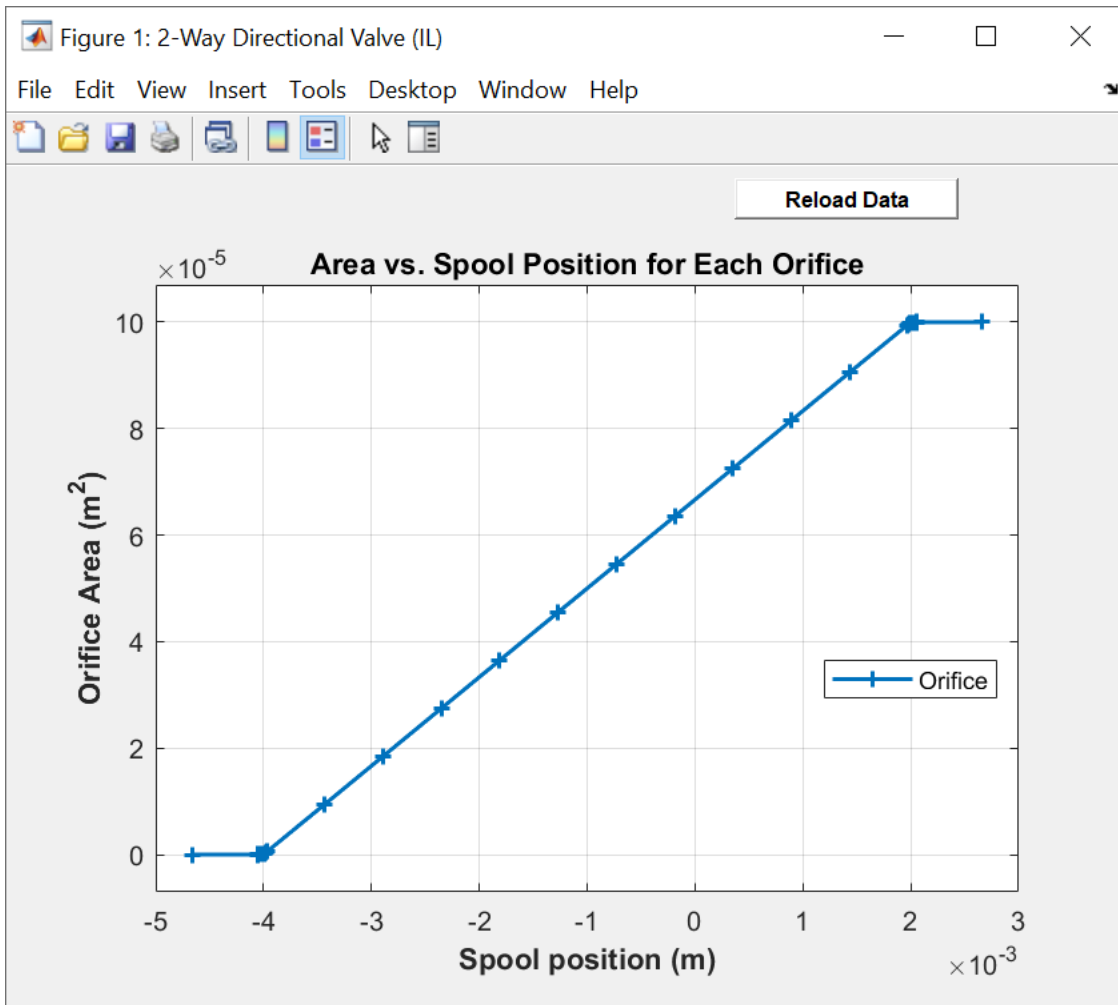
To visualize the spool offsets and displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the valve open area or volumetric flow rate as a function of spool position.

To update the data after changing the block parameters, click **Reload Data** in the figure window.

This figure shows the valve configuration with:

- **Spool position at maximum orifice area** set to  $2e-3$  m.
- **Spool travel between closed and open orifice** set to  $6e-3$  m.

All other parameters are at the default values.



**Faults**

When you set **Enable faults** to On, the valve opening stops at a specified spool position in response to how you set the **Fault trigger** parameter:

- Temporal — Fault occurs at the time you specify in the **Simulation time for fault event** parameter.
- External — Faults occur in response to an external trigger from port **Tr**.

You can choose the type of fault by using the **Spool position when faulted** parameter:

- Negative — The block freezes the valve at its smallest value. The table shows which value the block uses depending on the setting of the **Orifice parameterization** parameter.

Orifice parameterization Parameter Setting	Freeze Position Value
Linear - Area vs. spool travel	<b>Leakage area</b> parameter
Tabulated data - Area vs. spool travel	First element of the <b>Orifice area vector</b> parameter

Orifice parameterization Parameter Setting	Freeze Position Value
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop	First row of the <b>Volumetric flow rate table, <math>q(ds,dp)</math></b> parameter

- **Positive** — The valve freezes at its largest value. The table shows which value the block uses depending on the setting of the **Orifice parameterization** parameter.

Orifice parameterization Parameter Setting	Freeze Position Value
Linear - Area vs. spool travel	<b>Maximum opening area</b> parameter
Tabulated data - Area vs. spool travel	Last element of the <b>Orifice area vector</b> parameter
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop	Last row of the <b>Volumetric flow rate table, <math>q(ds,dp)</math></b> parameter

- **Maintain last value** — The valve freezes at its last value. The table shows which value the block uses depending on the setting of the **Orifice parameterization** parameter.

Orifice parameterization Parameter Setting	Freeze Position Value
Linear - Area vs. spool travel	The valve open area when the trigger occurred
Tabulated data - Area vs. spool travel	The valve open area when the trigger occurred
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop	Current position

Note that when you set **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop, the volumetric flow rate continues to change according to pressure changes in the valve after the valve freezes.

Due to numerical smoothing at the extremes of the valve area, the block applies a minimum area that is larger than the **Leakage area**, and a maximum that is smaller than the **Maximum orifice area**, in proportion to the **Smoothing factor** value.

After the fault triggers, the valve remains at the faulted area for the rest of the simulation.

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Isothermal liquid conserving port.

**B – Liquid port**

isothermal liquid

Isothermal liquid conserving port.

**Input****S – Spool displacement, m**

physical signal

Physical signal associated with the spool displacement, in m. A positive value causes the valve to open.

**Tr – External fault trigger**

physical signal

Physical signal port associated with the external fault trigger. Triggering occurs when the value is greater than 0.5.

**Dependencies**

To enable this port, set **Enable faults** to On and **Fault trigger** to External.

**Parameters****Model Parameterization****Orifice parameterization – Opening area relationship**

Linear - area vs. spool travel (default) | Tabulated data - Area vs. spool travel | Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Method the block uses to calculate the valve flow area. To learn more, see “Orifice Parameterizations” on page 1-12.

**Spool position at maximum orifice area – Spool offset at maximum area**

5e-3 m (default) | positive scalar

Position of the spool travel member when the valve is fully open. The default value represents a zero-lapped system. A positive, nonzero value represents an underlapped, or partially closed, system. A negative, nonzero value represents an overlapped system where the valve remains open over a range of displacements.

**Spool travel between closed and open orifice – Maximum spool stroke**

5e-3 m (default) | positive scalar

Spool offset at the maximum valve opened area.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. spool travel.

**Maximum orifice area – Area of fully open valve**1e-4 m<sup>2</sup> (default) | positive scalar

Maximum valve area experienced during simulation.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

**Leakage area – Valve gap area when in fully closed position**

$1e-10 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. The block maintains any area smaller than this value at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

**Spool travel vector – Spool opening distance values**

[0, .002, .004, .007, .017] m (default) | vector

Vector of control member travel distances. A positive value opens the valve. The values in this vector correspond one-to-one to values in the **Orifice area vector** parameter. The values must ascend from 0. The block interpolates the points linearly.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Area vs. spool travel.

**Orifice area vector – Valve opening area values**

[ $1e-09$ ,  $2.0352e-07$ ,  $4.0736e-05$ , .00011438, .00034356]  $\text{m}^2$  (default) | vector

Vector of valve area values for the tabular parametrization of opening area. The values in this vector correspond one-to-one with the elements in the **Spool travel vector** parameter. The first element of this vector is the leakage area, and the last element is the maximum valve area. The block interpolates the points linearly.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Area vs. spool travel.

**Spool travel vector, ds – Tabular spool opening distance values**

[0, .002, .004, .007, .017] m (default) | vector

Vector of control member travel distances. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. A positive displacement corresponds to valve opening. The values ascend from 0. The block interpolates the points linearly.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Pressure drop vector, dp – Tabular pressure drop values**

[.3, .5, .7] MPa (default) | vector

Vector of pressure drop values for the volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, ds** parameter for the 3-D dependent **Volumetric**

**flow rate table,  $q(ds,dp)$**  parameter. The values must be positive and ascending. The block interpolates the points linearly

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **Volumetric flow rate table, $q(ds,dp)$ – Volumetric flow rate for given spool travel and pressure drop**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] m<sup>3</sup>/s (default) | matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Spool travel vector,  $ds$**  parameter.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Discharge loss for a hydraulic structure. The default discharge coefficient for an valve in Simscape Fluids is 0.64.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

#### **Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

#### **Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.



**Dependencies**

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

**Pressure recovery — Whether to account for pressure increase in area expansions**

On (default) | Off

Whether to account for pressure increase when the fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

**Cross-sectional area at ports A and B — Valve area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at ports **A** and **B**. The block uses this area in the pressure-flow rate equation to determine the volumetric flow rate through the valve.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

**Faults****Enable faults — Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When a fault occurs, the block sets the valve area to the value specified in the **Spool position when faulted** parameter.

**Spool position when faulted — Set faulted characteristics**

Positive (default) | Negative | Maintain last value

Sets the faulted valve spool position. You can choose for the valve to seize when the spool is in the positive position, negative position, or at the position when the fault triggers.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Fault trigger — External or temporal trigger option**

Temporal (default) | External

Whether a fault occurs due to an external event or at a specified time.

- External — A physical signal at port **Tr** that is greater than 0.5 triggers a fault.
- Temporal — The block sets the valve area to the value specified in the **Spool position when faulted** parameter once the simulation reaches the time specified in the **Simulation time for fault event** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Simulation time for fault event — Time at which faulting is triggered**

5 s (default) | positive scalar

Simulation time when fault occurs.

**Dependencies**

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

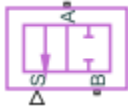
**See Also**

3-Way Directional Valve (IL) | 4-Way 3-Position Directional Valve (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Orifice (IL)

## 2-Way Directional Valve (G)

Controlled valve with two ports in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Directional Control Valves



### Description

The 2-Way Directional Valve (G) block represents a valve with two ports, **A** and **B**, and one flow path, **A-B**. The path runs through an orifice of variable width. The input signal specified at port **S** controls the position of the spool. The valve closes when the spool covers the orifice opening.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

### Valve Positions

The valve is continuously variable and it shifts smoothly between one normal and one working position.

When the instantaneous displacement of the spool at port **S** is zero, the valve reverts to the normal position where it is no longer operating. Unless the land of the spool is at an offset to the valve orifice, the valve is fully closed. The working position is the position the valve moves to when the spool is maximally displaced, in the positive direction, from the normal position. The orifice is then fully open.

The spool displacement that puts the valve in its working position depends on the offset of the land on the spool. The **Valve opening fraction offset** parameter specifies the block constant for the spool displacements of the ports.

### Orifice Opening Fractions

Between valve positions, the opening of the **A-B** orifice depends on where the land of the spool is, relative to the rim. This distance is the orifice opening, and the block normalizes this distance so that its value is a fraction of the maximum distance at which the orifice is fully open. The normalized variable is the orifice opening fraction.

The orifice opening fraction can range from 0, in the normal position, to 1, in the working position. The block calculates the opening fractions from the spool displacement and opening fraction offset. The displacement and offset are unitless fractions of the maximum land-orifice distance. The orifice opening fraction is:

$$h_{AB} = H_{AB} + \chi,$$

where:

- $h$  is the opening fraction of the **A-B** orifice. If the calculation returns a value outside of the range  $0 - 1$ , the block uses the nearest limit.
- $H$  is the value of the **Valve opening fraction offset** parameter. To allow for unusual valve configurations, the block imposes no limit on their values, although generally these will fall between  $-1$  and  $+1$ .
- $x$  is the normalized instantaneous displacement of the spool, specified by a physical signal at port **S**. To compensate for extreme opening fraction offsets, there is no limit on the signal value. The value is typically between  $0$  and  $+1$ .

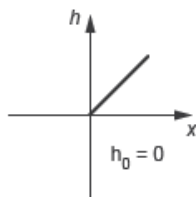
**Opening Fraction Offsets**

By default, the valve is fully closed when its control displacement is zero. In this state, the valve is zero-lapped.

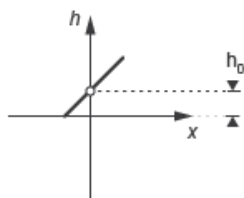
You can offset the lands of the spool to model an underlapped or overlapped valve. Underlapped valves are partially open in the normal position. Overlapped valves are fully closed slightly beyond the normal position. The figure shows how the orifice opening fractions vary with the instantaneous spool displacement:

- **Image I:** A zero-lapped valve. The opening fraction offset is zero. When the valve is in the normal position, the land of the spool completely covers the orifice.
- **Image II:** An underlapped valve. The opening fraction offset is positive. When the valve is in the normal position, the land of the spool partially covers the orifice.
- **Image III:** An overlapped valve. The opening fraction offset is negative. The land of the spool completely covers the orifice not only in the normal position but also over a small region of spool displacements around it.

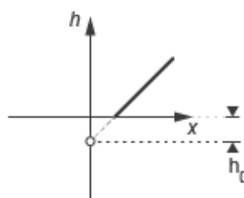
I.



II.



III.



**Control Position in Zero-Lapped, Underlapped, and Overlapped valves**

### Leakage Flow

The leakage flow ensures that no section of a fluid network becomes isolated. Isolated fluid sections can reduce the numerical robustness of the model, slow the rate of simulation and, in some cases, cause the simulation to fail. The **Leakage flow fraction** parameter represents the leakage flow area in the block as a small number greater than zero.

### Composite Structure

This block is a composite component comprising a single Orifice (G) block connected between ports **A**, **B**, and **S**. Refer to the Orifice (G) block for more detail on the valve parameterizations and block calculations.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

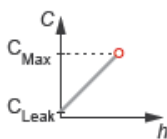
- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*. [1]
- **Orifice area** — The size of the flow restriction determines the block parametrization. [4]

### Opening Characteristics

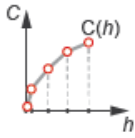
The flow characteristic relates the opening of the valve to the input that produces it, which is often the spool travel. The block expresses the opening as a sonic conductance, flow coefficient, or restriction area, depending on the setting of the **Valve parameterization** parameter. The control input is the orifice opening fraction, a function of the spool displacement specified at port **S**.

The flow characteristic is normally given at steady state, with the inlet at a constant, carefully controlled pressure. The flow characteristic depends only on the valve and can be linear or nonlinear. To capture the flow characteristics, use the **Opening characteristic** parameter:

- **Linear** — The measure of flow capacity is a linear function of the orifice opening fraction. As the opening fraction rises from 0 to 1, the measure of flow capacity scales from the specified minimum to the specified maximum.



- **Tabulated** — The measure of flow capacity is a general function, which can be linear or nonlinear, of the orifice opening fraction. The function is specified in tabulated form, with the independent variable specified by the **Opening fraction vector**



## Numerical Smoothing

When the **Opening characteristic** parameter is Linear, and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the orifice opening fraction. Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

## Assumptions and Limitations

- The Sonic conductance setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the Orifice area parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Input

#### S – Valve control signal, unitless

physical signal

Instantaneous displacement of the control member against its normal unactuated position, specified as a physical signal. The block normalizes the displacement against the maximum position of the control member that required to open the orifice fully. The signal is unitless and its instantaneous value is typically in the range between 0 and 1.

### Conserving

#### A – Valve opening

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### B – Valve opening

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

## Parameters

### Valve parameterization – Parameterization used to specify flow characteristics of orifice

Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization.
- **Orifice area** — The size of the flow restriction determines the block parametrization.

### **Opening characteristic — Method to calculate the opening characteristics of the valve**

Linear (default) | Tabulated

Method the block uses to calculate the opening area of the valve. The linear setting treats the opening area as a linear function of the orifice opening fraction. The tabulated setting allows for a general, nonlinear relationship you can specify in tabulated form.

### **Opening fraction vector — Control signal values at which to specify tabulated parameter data**

0 : 0.2 : 1 (default) | vector of positive numbers

Vector of control signal values at which to specify the chosen measure of flow capacity: **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector**. The control signal is between 0 and 1, with each value corresponding to an opening fraction of the resistive element. The greater the value, the greater the opening and easier the flow.

The opening fractions must increase monotonically across the vector from left to right. The size of this vector must be the same as the **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector** parameter.

#### **Dependencies**

To enable this parameter, set **Opening characteristic** to Tabulated.

### **Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

#### **Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Linear.

### **xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Leakage flow fraction — Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Cv flow coefficient vector — Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector — Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers



Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Kv flow coefficient`, and **Opening characteristic** to `Tabulated`.

#### Maximum sonic conductance — Sonic conductance corresponding to maximally open component

12  $\text{l}/(\text{bar}\cdot\text{s})$  (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Linear`.

#### Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Linear`.

#### Subsonic index — Exponent used to characterize mass flow in subsonic flow regime

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

#### ISO reference temperature — ISO 8778 reference temperature

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

#### ISO reference density — ISO 8778 reference density

1.185  $\text{kg}/\text{m}^3$  (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185  $\text{kg}/\text{m}^3$  in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12]  $1/(\text{bar}\cdot\text{s})$  (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Critical pressure ratio vector — Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Maximum orifice area — Flow area corresponding to maximally open component**

1e-4  $\text{m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Linear`.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Orifice area vector — Vector of orifice opening area values**

[1e-10, 2e-05, 4e-05, 6e-05, 8e-05, .0001]  $\text{m}^2$  (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

#### Dependencies

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Tabulated`.

#### Valve opening fraction offset – Opening fraction of the valve at a zero displacement signal

0 (default) | unitless scalar

Opening fraction of the valve when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance between the land of the spool and the orifice of the valve, normalized by the maximum allowed.

#### Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

#### Cross-sectional area at ports A and B – Flow area at gas ports

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

### Introduced in R2018b

#### Model gas systems using improved flow computations

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.

- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient** , respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

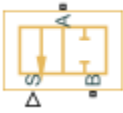
### See Also

Orifice (G) | 2-Way Directional Valve (G) | 3-Way Directional Valve (G) | 4-Way 3-Position Directional Valve (G)

## 2-Way Directional Valve (TL)

2-way directional valve in a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Directional Control Valves



### Description

The 2-Way Directional Valve (TL) block represents a two-way valve, such as a shut-off valve. Use this block to simulate a flow-reducing control element that responds to pressures in another part of the system.

The block uses a variable orifice to control the flow between ports **A** and **B**. The physical signal at port **S** triggers the spool motion to open or shut the valve. For more details about how the block calculates flow rate through a variable orifice, see Orifice (TL).

### Orifice Parameterizations

You can parameterize the valve opening linearly or by using tabulated data.

#### Linear

When you set **Orifice parameterization** to **Linear - Area vs. spool travel**, the opening area is a linear function of the spool travel distance.

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where

- $A_{orifice}$  is the opening area.
- $\Delta S$  is the spool travel distance input at port **S**.  $\Delta S = S - S_{max} + \Delta S_{max}$ .
- $\Delta S_{max}$  is the value of the **Spool travel between closed and open orifice** parameter.
- $A_{Leak}$  is the value of the **Leakage area** parameter.
- $A_{max}$  is the value of the **Maximum orifice area** parameter.

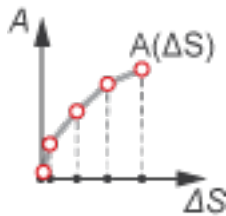
Note the linear scaling from  $A_{Leak}$  to  $A_{max}$  in the figure.



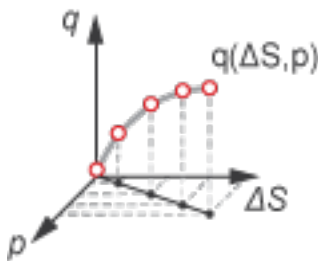
When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

### Tabulated

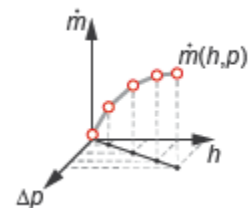
When you set **Orifice parameterization** to Tabulated data - Area vs. spool travel, the block uses the **Spool travel vector** and **Orifice area vector** parameters to define the relationship between  $A_{orifice}$  and  $\Delta S$  by interpolation.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Orifice area vector** parameter, respectively.



When you set **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop, the block uses the **Volumetric flow rate table,  $q(ds,dp)$** , **Pressure drop vector,  $dp$** , and **Spool travel vector,  $ds$**  parameters to define the volumetric flow rate,  $q(\Delta S, p)$ .



When you set **Orifice parameterization** to Tabulated data - Mass flow rate vs. opening and pressure drop the block calculates the mass flow rate directly from the spool position and the pressure drop across the valve. The relationship between the three variables can be nonlinear and it is given by the tabulated data in the **Spool travel vector,  $ds$** , **Pressure drop vector,  $dp$** , and **Mass flow rate table,  $\dot{m}(ds,dp)$**  parameters.



### Visualize Orifice Openings

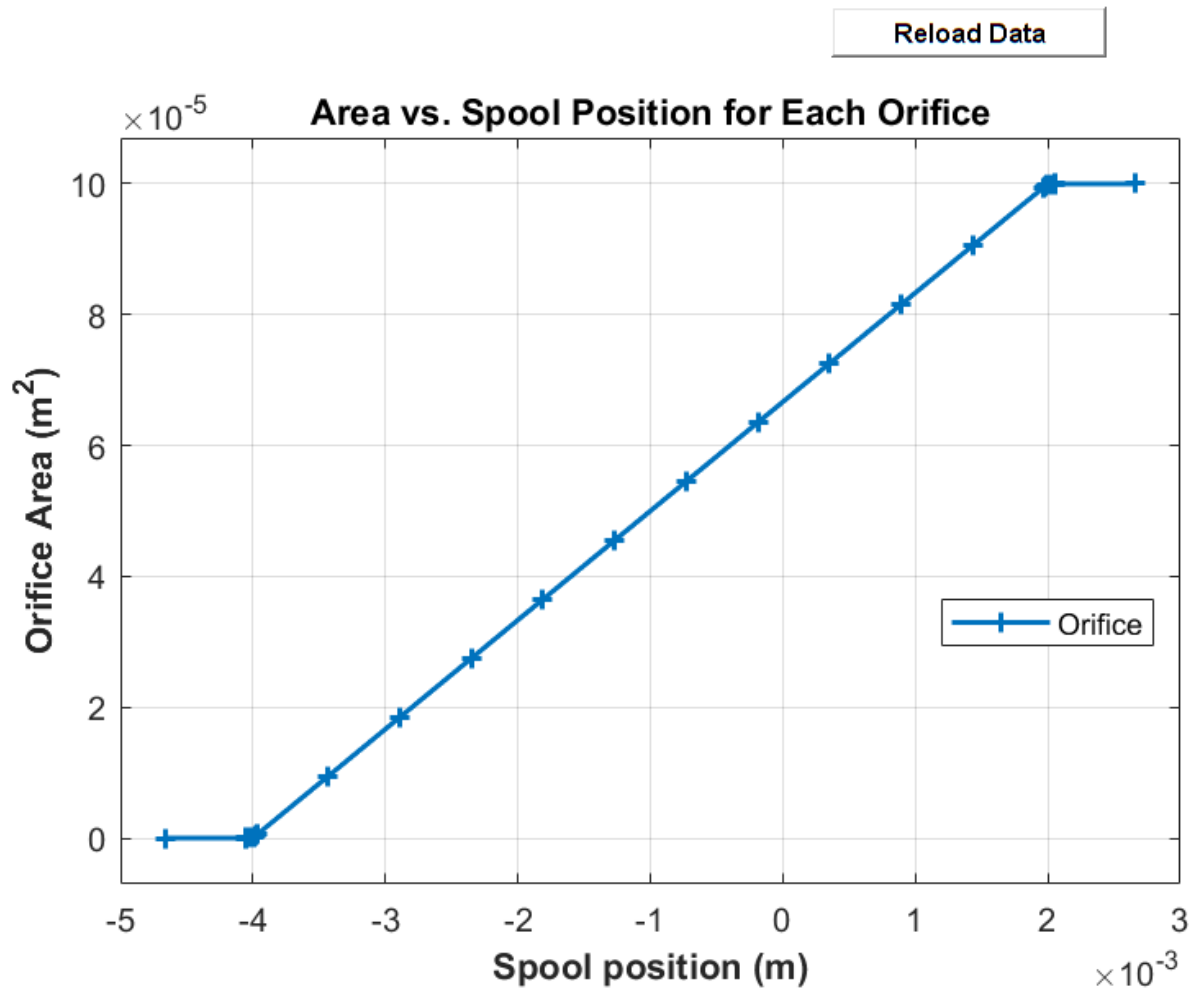
To visualize the spool offsets and displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the valve open area or volumetric flow rate as a function of spool position.

To update the data after changing the block parameters, click **Reload Data** in the figure window.

This figure shows the valve configuration with:

- **Spool position at maximum orifice area** set to  $2 \times 10^{-3}$  m.
- **Spool travel between closed and open orifice** set to  $6 \times 10^{-3}$  m.

All other parameters are at the default values.



## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port.

#### B — Liquid port

thermal liquid

Thermal liquid conserving port.

### Input

#### **S — Spool displacement, m**

physical signal

Physical signal associated with the spool displacement, in m. A positive value causes the valve to open.

## Parameters

### Model Parameterization

#### **Orifice parameterization — Opening area relationship**

Linear - Area vs. spool travel (default) | Tabulated data - Area vs. spool travel |  
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop |  
Tabulated data - Mass flow rate vs. spool travel and pressure drop

Method the block uses to calculate the valve flow area.

#### **Spool position at maximum orifice area — Spool offset at maximum area**

5e-3 m (default) | positive scalar

Position of the spool travel member when the valve is fully open.

#### **Spool travel between closed and open orifice — Maximum spool stroke**

5e-3 m (default) | positive scalar

Spool offset at the maximum valve opened area.

### Dependencies

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

#### **Maximum orifice area — Area of fully open valve**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum valve area experienced during simulation.

### Dependencies

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

#### **Leakage area — Valve gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. The block maintains any area smaller than this value at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

### Dependencies

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

#### **Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]



Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Linear - area vs. spool travel.

#### Spool travel vector — Spool opening distance values

[0, .002, .004, .007, .017] m (default) | vector

Vector of control member travel distances. A positive value opens the valve. The values in this vector correspond one-to-one to values in the **Orifice area vector** parameter. The values must ascend from 0. The block interpolates the points linearly.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Tabulated data - Area vs. spool travel.

#### Orifice area vector — Valve opening area values

[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | vector

Vector of valve area values for the tabular parametrization of opening area. The values in this vector correspond one-to-one with the elements in the **Spool travel vector** parameter. The first element of this vector is the leakage area, and the last element is the maximum valve area. The block interpolates the points linearly.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Tabulated data - Area vs. spool travel.

#### Discharge coefficient — Discharge coefficient

0.7 (default) | positive scalar

Discharge loss for a hydraulic structure.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

#### Critical Reynolds number — Upper Reynolds number limit for laminar flow

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

**Pressure recovery — Whether to account for pressure increase in area expansions**

On (default) | Off

Whether to account for pressure increase when the fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

**Spool travel vector, ds — Tabular spool opening distance values**

[0, .002, .004, .007, .017] m (default) | vector

Vector of control member travel distances. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. A positive displacement corresponds to valve opening. The values ascend from 0. The block interpolates the points linearly.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Pressure drop vector, dp — Tabular pressure drop values**

[.3, .5, .7] MPa (default) | vector

Vector of pressure drop values for the volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, ds** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. The values must be ascending. The block interpolates the points linearly.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Volumetric flow rate table, q(ds,dp) — Volumetric flow rate for given spool travel and pressure drop**[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] m<sup>3</sup>/s (default) | matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of elements in the **Spool travel vector, ds** parameter.
- *N* is the number of elements in the **Pressure drop vector, dp** parameter.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Mass flow rate table, mdot(ds,dp) — Mass flow rate for given spool travel and pressure drop**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default) | matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- $M$  is the number of elements in the **Spool travel vector,  $ds$**  parameter.
- $N$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### Reference inflow temperature — Temperature at which mass flow rate data is specified

293.15 K (default) | positive scalar

Temperature at which the tabulated mass flow rate data is specified.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### Reference inflow pressure — Pressure at which mass flow tabulated data is specified

0.101325 MPa (default) | positive scalar

Pressure at which the tabulated mass flow rate data is specified. The block uses this parameter to calculate a third reference parameter, the reference density.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### Cross-sectional area at ports A and B — Valve area at conserving ports

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area at ports **A** and **B**. The block uses this area in the pressure-flow rate equation to determine the volumetric flow rate through the valve.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to either:

- Tabulated data - Area vs. spool travel
- Linear - area vs. spool travel

## Version History

Introduced in R2016a

### Right-click blocks to view opening characteristic plots

You can view the plot of the area or volumetric flow rate with respect to spool position for each orifice by right-clicking the block and selecting **Fluids > Plot Valve Characteristics**.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Orifice (TL) | 3-Way Directional Valve (TL) | 4-Way 3-Position Directional Valve (TL) | Check Valve (TL)

## 3-Position Valve Actuator

Actuator for three-position valves



### Library

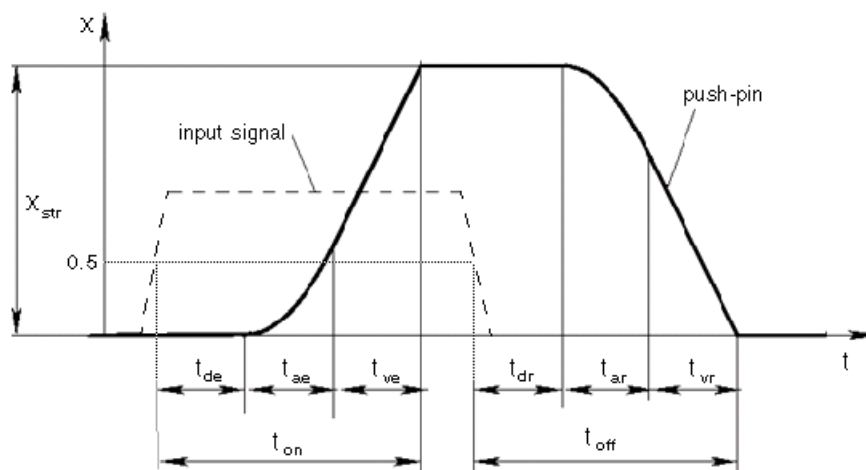
Valve Actuators

### Description

The 3-Position Valve Actuator block represents an actuator that you can use with directional valves to control their position. This actuator can drive a three-position valve. The block is developed as a data-sheet-based model and all its parameters are generally provided in catalogs or data sheets. The key parameters are the stroke, switch-on, and switch-off times.

The block has two signal inputs associated with the activation signals for electromagnets A or B. It produces a physical output signal that can be associated with a mechanical translational or rotational push-pin motion. Connect the block output to the directional valve control port.

The actuator is represented as an ideal transducer, where output does not depend on the load exerted on the push-pin and the push-pin motion profile remains the same under any loading conditions. The motion profile represents a typical transition curve for electromagnetic actuators. The following figure shows the motion profile for a case when the input signal is applied long enough for the push-pin to reach the end of the stroke ( $x_{str}$ ), and then the input signal is removed, causing the push-pin to return to initial position:



The push-pin is actuated when the input signal value crosses the threshold of 50% of the nominal input signal, where **Nominal signal value** is a block parameter. The motion is divided into three phases, equal in time: delay ( $t_{de}$ ), motion at constant acceleration ( $t_{ae}$ ), and motion at constant

velocity ( $t_{ve}$ ). The motion stops when the switch-on time ( $t_{on}$ ) elapses. At this moment, the push-pin reaches the specified stroke value ( $x_{str}$ ). To return the push-pin into initial position, the control signal must be removed, which causes the push-pin to retract. The retract motion also consists of three phases, equal in time: delay ( $t_{dr}$ ), motion at constant acceleration ( $t_{ar}$ ), and motion at constant velocity ( $t_{vr}$ ). It follows exactly the same profile but “stretches” over the switch-off time. **Switching-on time** and **Switching-off time** are the block parameters.

The signal applied to port A causes the output to move in positive direction. To shift the push-pin in negative direction, you must apply the signal to port B. Only one control signal can be applied at a time. This means that if the actuator is being controlled by the signal at port A, the push-pin must be allowed to return to initial position before the control signal at port B can be processed. The transition in any direction can be interrupted at any time by changing the input signal. If motion is interrupted, the switch-on or switch-off times are proportionally decreased depending on the instantaneous push-pin position.

Only positive signals activate the actuator. In other words, negative signals at ports A and B have no effect on the actuator, which is similar to the behavior of electromagnetically controlled 3-position directional valves.

## Basic Assumptions and Limitations

Push-pin loading, such as inertia, spring, hydraulic forces, and so on, is not taken into account.

## Parameters

### Push-pin stroke

The push-pin stroke. The default value is 0.01 m.

### Switching-on time

Time necessary to fully extend the push-pin after the control signal is applied. The default value is 0.1 s.

### Switching-off time

Time necessary to retract push-pin from fully extended position after the input signal is removed. The default value is 0.1 s.

### Nominal signal value

Sets the value of the nominal input signal. The output motion is initiated as the input signal crosses 50% value of the nominal signal. Other than that, the input signal has no effect on the motion profile. This parameter is meant to reproduce the rated voltage feature of an electromagnet. The default value is 24.

### Initial position

Specifies the initial position of the push-pin. The parameter can have one of three values: `Extended positive`, `Extended negative`, or `Neutral`. The default value is `Neutral`.

In selecting the initial position, consider the following:

- The steady-state push-pin position always corresponds to the control signal. In other words, zero signal keeps the push-pin at `Neutral`, positive signal — at `Extended positive`, and negative signal — at `Extended negative`.

- At the start of simulation, if there is a discrepancy between the initial position of the push-pin, as specified by the **Initial position** parameter, and the control signal, the push-pin immediately starts moving towards the steady-state position designated by the control signal.

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Initial position**

All other block parameters are available for modification.

### Ports

The block has the following ports:

A

Physical signal input port associated with the port A input signal.

B

Physical signal input port associated with the port B input signal.

The block also has one physical signal output port, which is associated with the output signal (push-pin displacement).

### Examples

In the “3-Position Valve Actuator” example, all three actuators are set to different strokes, switch-on and switch-off times, and initial positions. If the initial position is not **Neutral** and the control signal at the beginning of simulation equals zero, the push-pin starts moving towards neutral position, as the actuators A and C show in the example.

## Version History

**Introduced in R2006a**

### Extended Capabilities

#### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

2-Position Valve Actuator | Hydraulic Double-Acting Valve Actuator | Hydraulic Single-Acting Valve Actuator | Proportional and Servo-Valve Actuator

## 3-Way Directional Valve

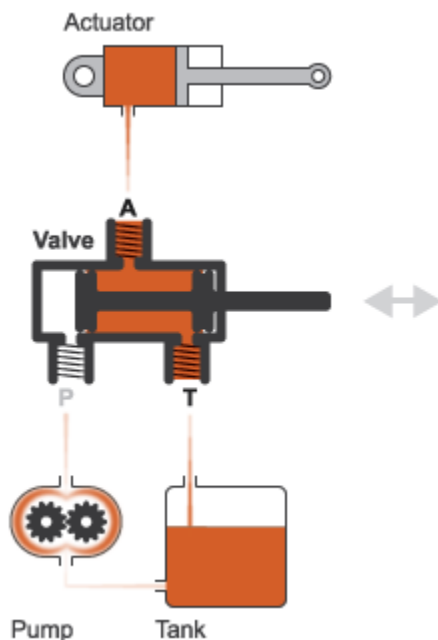
Three-port two-position directional control valve

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Directional Valves



### Description

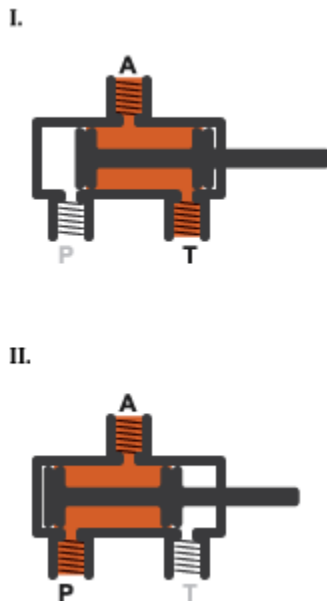
The 3-Way Directional Valve block represents a directional control valve with three ports and two positions, or flow paths. The ports connect to what in a typical model are a hydraulic pump (port **P**), a storage tank (port **T**), and a single-acting actuator (port **A**). Fluid can flow from the pump to the actuator via path **P-A** and from the actuator to the tank via path **A-T**.



### Typical Valve Setup

In the default configuration, one valve position corresponds to the **A-T** flow path maximally open and the **P-A** flow path maximally closed (position **I** in the figure). The second valve position corresponds to the **P-A** flow path maximally open and the **A-T** flow path maximally closed (position **II** in the figure). A translating spool serves as the valve control member and determines the position that the valve is in—**I**, **II**, or in between.





### Valve Positions

Physical signal port **S** controls the spool displacement. In the default configuration, a zero displacement corresponds to a fully closed valve between positions **I** and **II**. A negative displacement shifts the spool toward valve position **I**. A positive displacement signal shifts the spool toward valve position **II**. The spool displacement acts indirectly by setting the spool position relative to each flow path—a length known here as the *orifice opening*. The orifice opening in turn determines the opening area of the respective flow path.

### Orifice Openings and Offsets

The orifice opening of a flow path depends partly on its *opening offset*—the orifice opening of a flow path at zero spool displacement. The block models only the dynamic effects of the opening offsets. An offset can be due to a change in distance between ports or spool lands—the thick disks built into the spool to obstruct flow. It can also be due to a change in the thicknesses of the spool lands. The orifice openings are computed separately for each flow path in terms of the respective opening offset:

$$h_{PA} = h_{PA0} + \chi,$$

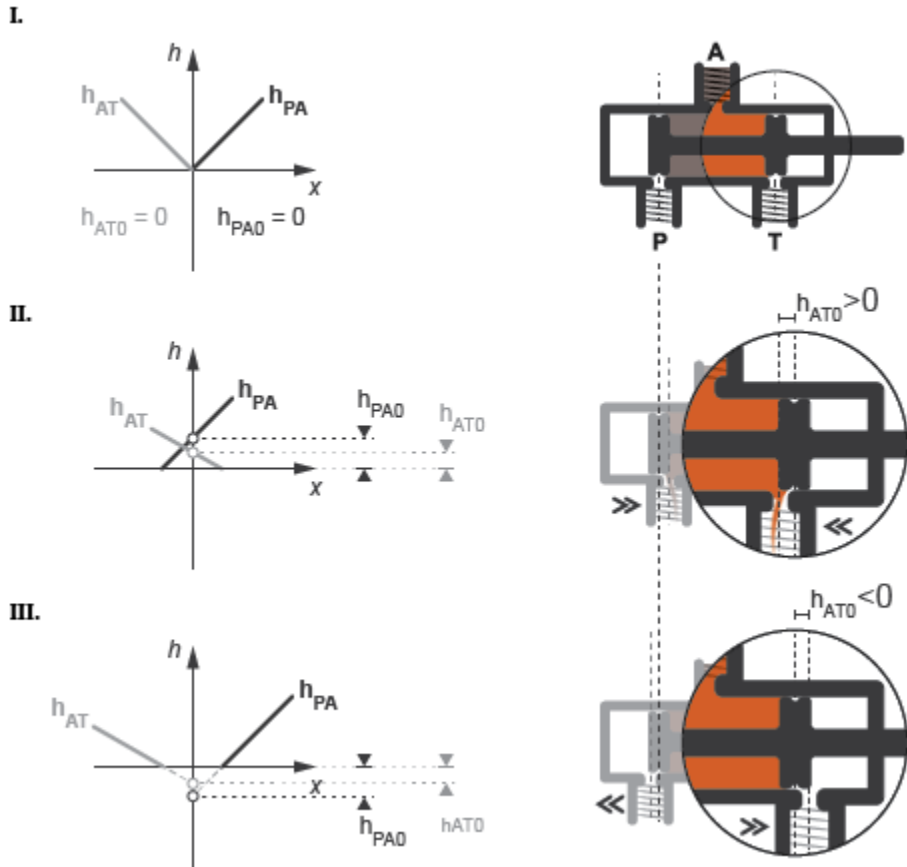
$$h_{AT} = h_{AT0} - \chi,$$

where:

- $h_{PA}$  and  $h_{AT}$  are the orifice openings of the **P-A** and **A-T** flow paths. The orifice openings are computed during simulation.
- $h_{PA0}$  and  $h_{AT0}$  are the opening offsets of the **P-A** and **A-T** flow paths. The opening offsets are specified in the **Valve opening offsets** tab.
- $\chi$  is the spool displacement relative to what in the zero-offset case is a fully closed valve. The spool displacement is specified through physical signal port **S**.

The figure shows the effects of the opening offsets on the orifice openings. Plot **I** corresponds to the default configuration with both opening offsets equal to zero. Plot **II** corresponds to a valve with both

opening offsets greater than zero and plot **III** to a valve with both opening offsets smaller than zero. These cases are similar in behavior to zero-lapped (**I**), underlapped (**II**) and overlapped (**III**) valves. The valve schematics to the right show what the offsets might look like for the **A-T** flow path.



### Zero (I), Positive (II), and Negative (III) Opening Offsets

An underlapped valve is always partially open and allows some flow at all spool displacements. An overlapped valve is fully closed over an extended range of spool displacements and requires longer spool travel to open. The table summarizes the opening offsets for zero-lapped, underlapped, and overlapped valves. Other configurations are possible—e.g., with one opening offset positive and the other negative.

Valve Lapping	Opening Offsets
Zero-lapped (default)	Both zero
Underlapped	Both positive
Overlapped	Both negative

### Opening Area Parameterizations

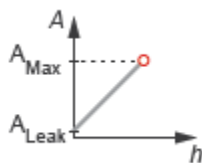
The **Model parameterization** setting determines the calculations used for the opening areas of the flow paths—or, in the Pressure-flow characteristic case, the volumetric flow rates. The calculations are based on orifice parameters or tabulated data sets specified in the **Model**

**Parameterization** tab. The block uses the same data for both flow paths if the **Area characteristics** parameter in the **Basic Parameters** tab is set to **Identical** for all flow paths and different data otherwise. Model parameterizations that you can select include:

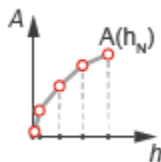
- **Maximum area and opening** — Specify the maximum opening area and the corresponding orifice opening. The opening area is a linear function of the orifice opening,

$$A_{AT} = \frac{A_{AT,Max}}{h_{AT,Max}} h_{AT} + A_{Leak},$$

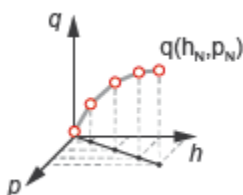
where  $A$  is the opening area and  $h$  the orifice opening of a given flow path. The subscript **Max** refers to a fully open orifice and the subscript **Leak** to a fully closed orifice—one with internal leakage flow area only. The figure shows a plot of the linear function  $A(h)$ .



- **Area vs. opening table** — Specify the opening area at discrete orifice openings as a 1-D lookup table. The opening area is computed for a given orifice opening by interpolation or extrapolation of the tabulated data. The figure shows a conceptual plot of the tabulated function  $A(h)$ .



- **Pressure-flow characteristic** — Specify the volumetric flow rate at discrete orifice openings and pressure differentials as a 2-D lookup table. The opening area is computed for a given orifice opening and pressure differential by interpolation or extrapolation of the tabulated data. The figure shows a conceptual plot of the tabulated function  $q(h, p)$ .



### Flow Regime and Internal Leakage

Volumetric flow rates are computed analytically in the **Maximum area and opening** and **Area vs. opening table** parameterizations. The calculations are based on additional block parameters such as the flow discharge coefficient and account for the effects of flow regime—laminar or turbulent. Regime transition occurs at the specified critical laminar flow ratio or critical Reynolds number.

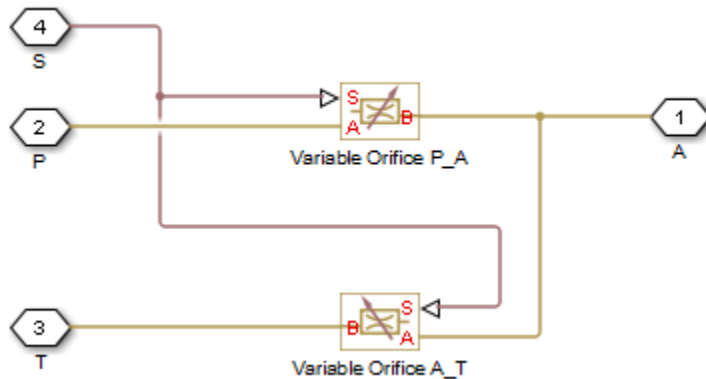
The Maximum area and opening and Area vs. opening table parameterizations also account for a small leakage area associated with the valve spool-to-bore clearance. The leakage area ensures that portions of the hydraulic network never become isolated when a flow path is closed. Isolated, or “hanging”, network portions affect computational efficiency and can cause simulation to fail.

The effects of flow regime and internal leakage are assumed to be reflected in the tabulated flow rate data specified directly in the Pressure-flow characteristic parameterization.

### Structural Component Diagram

The block is a composite component with two Variable Orifice blocks driven by a single physical signal. Block Variable Orifice P\_A represents the **P-A** flow path. Block Variable orifice A\_T represents the **A-T** flow path. The physical signal is specified through Connection Port block **S**.

The **Orifice orientation** block parameters are set so that a positive signal acts to open Variable Orifice P\_A while closing Variable Orifice A\_T. A negative signal has the opposite effect, acting to open Variable Orifice A\_T while closing Variable Orifice P\_A.



### Valve Structural Diagram

#### Assumptions

- Fluid inertia is ignored.
- Spool loading due to inertial, spring, and other forces is ignored.
- All valve orifices are assumed identical in size unless otherwise specified.

### Ports

#### Input

**S — Spool displacement, m**

physical signal

Physical signal input port for the spool displacement.

#### Conserving

**P — Supply line orifice**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) port associated with the supply line orifice.

#### **T – Return line orifice**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) port associated with the return line orifice.

#### **A – Actuation line orifice**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) port associated with the actuation orifice.

## Parameters

### Basic Parameters

#### **Area characteristics – Symmetry of the flow path opening characteristics**

Identical for all flow paths (default) | Different for each flow path

Choice of different or identical flow path opening characteristics. Select **Different** for each flow path to specify flow path parameters or tabulated data separately for each flow path.

#### **Model parameterization – Types of valve parameters to use as input**

Maximum area and opening (default) | Area vs. opening table | Pressure-flow characteristic

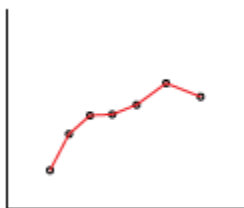
Parameterization of the valve model. Options include:

- **By maximum area and opening** — Specify the maximum orifice opening and opening area. The opening area varies linearly with the spool displacement specified at physical signal port **S**.
- **By area vs. opening table** — Specify the flow path opening area at discrete orifice openings as a 1-D lookup table. The opening area is computed by interpolation or extrapolation of the tabulated data.
- **By pressure-flow characteristic** — Specify the flow path volumetric flow rates at discrete orifice openings and pressure differentials. The flow rate is computed by interpolation or extrapolation of the tabulated data.

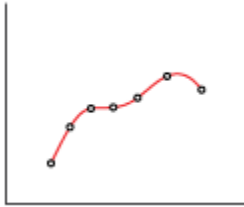
#### **Interpolation method – Method of computing values inside the lookup table range**

Linear (default) | Smooth

Method of computing values inside the tabulated data range. The **Linear** method joins adjacent data points with straight line or surface segments with generally discontinuous slope at the segment boundaries. Surface segments are used in the 2-D lookup table specified in the **Pressure-flow characteristic** model parameterization.



The **Smooth** method replaces the straight segments with curved versions that have continuous slope everywhere inside the tabulated data range. The segments form a smooth line or surface passing through all of the tabulated data points without the discontinuities in first-order derivatives characteristic of the **Linear** interpolation method.



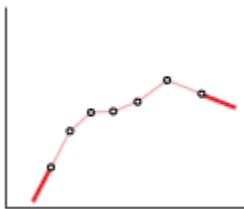
### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to **By area vs. opening table** or **Pressure-flow characteristic**.

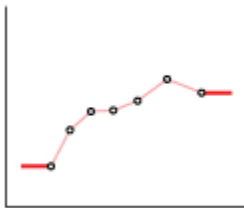
### Extrapolation method — Method of computing values outside of the lookup table range

Linear (default) | Nearest

Method of computing values outside of the tabulated data range. The **Linear** method extends the line segment drawn between the last two data points at each end of the data range outward with a constant slope.



The **Nearest** method extends the last data point at each end of the data range outward as a horizontal line with constant value.



### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to **By area vs. opening table** or **Pressure-flow characteristic**.

### Flow discharge coefficient — Semi-empirical parameter for valve capacity characterization

0.7 (default) | unitless scalar between 0 and 1

Ratio of the actual and theoretical flow rates through the valve. This parameter depends on the geometrical properties of the valve. Values are usually provided in textbooks and manufacturer data sheets.

#### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening` table.

#### Leakage area — Internal leakage area between valve inlets

1e-12 m<sup>2</sup> (default) | positive scalar in units of area

Total area of internal leaks in the completely closed state. The purpose of this parameter is to maintain the numerical integrity of the fluid network by preventing a portion of that network from becoming isolated when the valve is completely closed.

#### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening` table.

#### Laminar transition specification — Choice of parameter used to define the laminar-turbulent transition

Pressure ratio (default) | Reynolds number

Select the parameter to base the laminar-turbulent transition on. Options include:

- **Pressure ratio** — Flow transitions between laminar and turbulent at the pressure ratio specified in the **Laminar flow pressure ratio** parameter. Use this option for the smoothest and most numerically robust flow transitions.
- **Reynolds number** — The transition occurs at the Reynolds number specified in the **Critical Reynolds number** parameter. Flow transitions are more abrupt and can cause simulation issues at near-zero flow rates.

#### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening` table.

#### Laminar flow pressure ratio — Pressure ratio at the laminar-turbulent flow transition

0.999 (default) | unitless scalar between 0 and 1

Pressure ratio at which the flow transitions between the laminar and turbulent regimes. The pressure ratio is the fraction of the outlet pressure over the inlet pressure.

#### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening` table and the **Laminar transition specification** parameter is set to `Pressure ratio`.

#### Critical Reynolds number — Reynolds number at the laminar-turbulent flow transition

12 (default) | unitless positive scalar

Maximum Reynolds number for laminar flow. This parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value, 12, corresponds to a round orifice in thin material with sharp edges.

#### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to By maximum area and opening or By area vs. opening table and the **Laminar transition specification** parameter is set to Reynolds number.

#### Model Parameterization: Maximum area and opening

##### Maximum opening — Orifice opening at which the opening area is a maximum

0.005 m (default) | positive scalar with units of length

Orifice opening at which the opening area of a flow path is a maximum. The maximum opening is the same for all flow paths when this parameter is exposed. For the orifice opening definitions, see “Orifice Openings and Offsets” on page 1-43.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Maximum area and opening.

##### Maximum opening area — Maximum cross-sectional area of a flow path

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of a flow path. The maximum opening areas are the same for all paths when this parameter is exposed. For the opening area calculations, see “Opening Area Parameterizations” on page 1-44.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Maximum area and opening.

##### P-A, maximum opening — P-A orifice opening at which the opening area is a maximum

0.005 m (default) | positive scalar with units of length

Spool position relative to the **P-A** flow path at which the **P-A** opening area is equal to the **P-A, maximum opening area** parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

##### P-A, maximum opening area — Maximum flow area of the P-A flow path

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **P-A** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Area Parameterizations” on page 1-44.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.



**A-T, maximum opening — A-T Orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Spool position relative to the **A-T** flow path at which the **A-T** opening area is equal to the **A-T, maximum opening area** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**A-T, maximum opening area — Maximum flow area of the A-T flow path**0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **P-A** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Area Parameterizations” on page 1-44.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**Model Parameterization: Area vs. opening table****Opening vector — Orifice openings at which to specify the flow path opening areas**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of orifice openings used to construct the opening area 1-D lookup table for all flow paths. The opening characteristics are identical for all flow paths when this parameter is exposed. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Area vs. opening table.

**Opening area vector — Opening areas corresponding to the orifice openings specified in the Opening vector parameter**[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of flow path opening areas corresponding to the specified orifice openings. The number of elements in the array must match the number of elements in the **Opening vector** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Area vs. opening table.

**P-A, opening vector — P-A orifice openings at which to specify the P-A opening area**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **P-A** orifice openings used to construct the opening area 1-D lookup table for the **P-A** flow path. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

#### **P-A, opening area vector — P-A opening areas corresponding to the orifice openings specified in the P-A, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **P-A** opening areas corresponding to the specified **P-A** orifice openings. The number of elements in the array must match the number of elements in the **P-A, opening vector** parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

#### **A-T, opening vector — A-T orifice openings at which to specify the A-T opening area**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **A-T** orifice openings used to construct the opening area 1-D lookup table for the **A-T** flow path. The number of elements in the array determines the number of elements in the table.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

#### **A-T, opening area vector — A-T opening areas corresponding to the orifice openings specified in the A-T, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **A-T** opening areas corresponding to the specified **A-T** orifice openings. The number of elements in the array must match the number of elements in the **A-T, opening vector** parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

#### **Model Parameterization: Pressure-flow characteristic**

#### **Opening vector, s — Orifice openings at which to specify the flow rate tabulated data**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of orifice openings used to construct the volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of rows in the table. The array must increase from left

to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### Pressure differential vector, **dp** – Pressure differentials at which to specify the flow rate data

[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0] Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of columns in the table. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### Volumetric flow rate table, **q(s, dp)** – Volumetric flow rates at the specified orifice openings and pressure differentials

5-by-6 matrix with elements between -0.0344 and 0.0344 m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates corresponding to the specified orifice openings and pressure differentials. The number of rows must match the number of elements in the **Opening vector, s** parameter. The number of columns must match the number of elements in the **Pressure differential vector, dp** parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### P-A, opening vector, **s** – Orifice openings at which to specify the P-A flow rate data

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **P-A** orifice openings used to construct the **P-A** volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of rows in the table. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Pressure-flow characteristic.

**P-A, pressure differential vector, dp — Pressure differentials at which to specify the P-A flow rate data**

[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0] Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the **P-A** flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**P-A, volumetric flow rate table, q(s,dp) — Volumetric flow rates at the specified P-A orifice openings and pressure differentials**

5-by-6 matrix with elements between -0.0344 and 0.0344 m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates through the **P-A** flow path at the **P-A** orifice openings and pressure differentials. The number of rows must match the number of elements in the **P-A, opening vector, s** parameter. The number of columns must match the number of elements in the **P-A, pressure differential vector, dp** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**A-T, opening vector, s — Orifice openings at which to specify the A-T flow rate data**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **A-T** orifice openings used to construct the **A-T** volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of rows in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**A-T, pressure differential vector, dp — Pressure differentials at which to specify the A-T flow rate data**

[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0] Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the **A-T** flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

#### **A-T, volumetric flow rate table, $q(s, dp)$ – Volumetric flow rates at the specified A-T orifice openings and pressure differentials**

5-by-6 matrix with elements between  $-0.0344$  and  $0.0344$  m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates through the **A-T** flow path at the **A-T** orifice openings and pressure differentials. The number of rows must match the number of elements in the **A-T, opening vector,  $s$**  parameter. The number of columns must match the number of elements in the **A-T, pressure differential vector,  $dp$**  parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

#### Valve Opening Offsets

##### **Between P-A – P-A orifice opening at zero spool displacement**

0 m (default) | scalar number with units of length

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of 0 corresponds to a zero-lapped valve.

##### **Between A-T – A-T orifice opening at zero spool displacement**

0 m (default) | scalar number with units of length

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of 0 corresponds to a zero-lapped valve.

## Version History

Introduced in R2017a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

2-Way Directional Valve | 4-Way Directional Valve

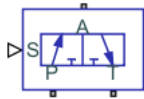
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 3-Way Directional Valve (IL)

3-way flow control valve in an isothermal system

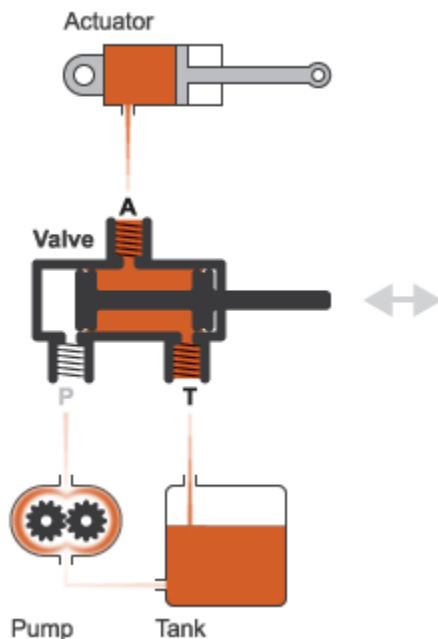
**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



### Description

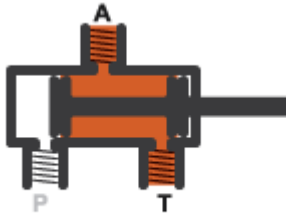
The 3-Way Directional Valve (IL) block models a valve with three openings in an isothermal liquid network, typically between an actuator, pump, and tank. The valve operation is controlled by a single spool displaced according to the signal at port **S**. You can set the baseline configuration of your valve by specifying the orifices that are open when the spool moves in the positive direction and negative directions in the **Positive spool position open connections** and **Negative spool position open connections** parameters, respectively.

You can set the model for valve opening in the **Orifice parameterization** parameter as a linear relationship or function of user-provided data, which can be applied to one or all flow paths in the valve.

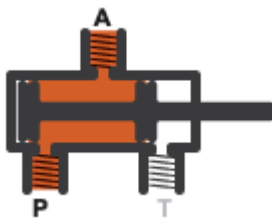


### Example Valve Configuration

In this configuration, **Positive spool position open connections** is set to A-T only. When the signal at port **S** moves the spool to a positive position, the path between ports **A** and **T** is open to flow. The paths between ports **P** and **A** and between ports **P** and **T** are closed:



In this configuration, **Negative spool position open connections** is set to P-A only. When the signal at port **S** moves the spool to a negative position, the path between ports **P** and **A** is open to flow and the paths between ports **T** and **A** and between ports **P** and **T** are closed:



You can open the path between ports **P** and **T** by setting either **Positive spool position open connections** or **Negative spool position open connections** to P-T only or P-A, A-T, and P-T.

A flow path can be open in either the positive or negative spool positions, but not both.

### Valve Orifice Parameterizations

The **Orifice parameterization** sets the method for calculating the valve open area. The calculations are based either on the orifice parameters or tabulated data sets specified in the **Model Parameterization** tab. The block uses the same data for all flow paths if **Area characteristics** is set to **Identical for all flow paths**; otherwise, individual values are applied in the **Different for all flow paths** setting. The orifice parameterizations are:

- Linear - area vs. spool travel

The opening area is a linear function of the spool travel distance and the signal received at port **S**:

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where:

- $A_{max}$  is the **Maximum orifice area**.
- $A_{leak}$  is the **Leakage area**.
- $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.
- $\Delta S$  is the spool travel distance. For flow paths that are open in the positive position:

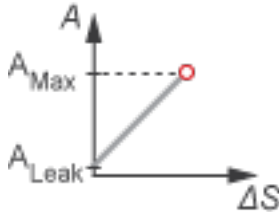
$$\Delta S = S_{orifice\_max} - \Delta S_{max} + S,$$

and for flow paths that are open in the negative position:



$$\Delta S = S_{orifice\_max} + \Delta S_{max} - S,$$

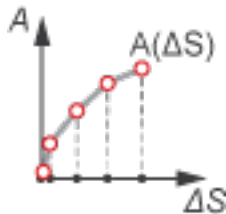
where  $S_{orifice\_max}$  is the **Spool position at maximum orifice area**.



When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

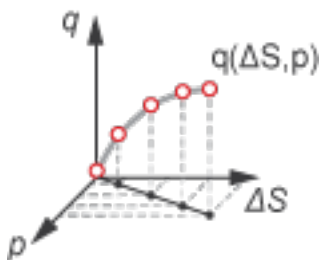
- Tabulated data - Area vs. spool travel

Provide spool travel vectors for your system or for individual flow paths between ports **P** and **A**, **A** and **T**, and **P** and **T**. This data will be used to calculate the relationship between the orifice opening area and spool travel distance. Interpolation is used to determine the opening area between given data points.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Opening area vector**, respectively.



- Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Provide spool travel and pressure drop vectors. The volumetric flow rate is calculated based on the relationship between pressure change and the spool travel distance. Interpolation is used to determine flow rate between given data points. The mass flow rate is the product of the volumetric flow rate and the local density.



### Visualize Orifice Openings

To visualize spool offsets and displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the orifices selected in the **Valve Configuration** settings. The parameterization selection sets the axes, which are either:

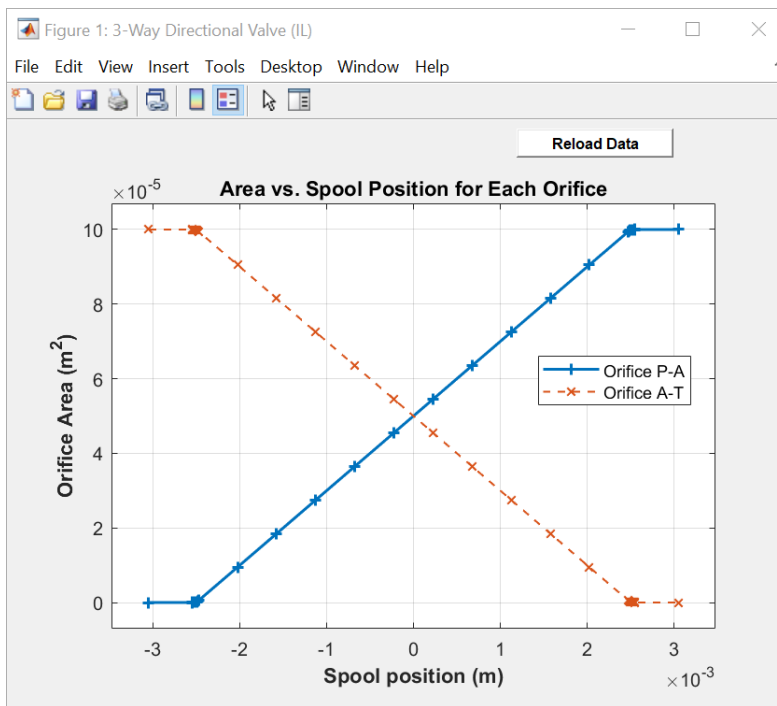
- Orifice area versus spool position
- Volumetric flow rate versus spool position, queried at a specific pressure differential

To update the data after changing the block parameters, click **Reload Data** on the figure window.

This image shows an example valve configuration. In the **Valve Configuration** settings:

- **Positive spool position open connections** is P-A only.
- **Negative spool position open connections** is A-T only.

All other spool positions are at the default values.



### Example Spool Position Visualization

#### Faults

When faults are enabled, the valve open area becomes stuck at a specified spool position in response to one of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **Tr**.

Three fault options are available in the **Spool position when faulted** parameter:

- **Positive** — The spool position freezes in the positive position, opening the **Positive spool position open connections** flow paths to their maximum value. The flow paths that are only open in the **Negative spool position open connections** and **Neutral spool position open connections** are closed.
- **Negative** — The spool position freezes in the negative position, opening the **Negative spool position open connections** flow paths to their maximum value. The flow paths that are only

open in the **Positive spool position open connections** and **Neutral spool position open connections** are closed.

- **Maintain last value** — The valve freezes at the spool position when the trigger occurs.

Due to numerical smoothing at the extremes of the valve area, in the linear parameterization, the minimum area applied is larger than the **Leakage area**, and the maximum is smaller than the **Maximum orifice area**, in proportion to the **Smoothing factor** value.

Once triggered, the valve remains at the faulted area for the rest of the simulation.

### Predefined Parameterization

Pre-parameterization of the 3-Way Directional Valve (IL) block with manufacturer data is available. This data allows you to model a specific supplier component.

To load a predefined parameterization,

- 1 Click the "Select a predefined parameterization" hyperlink in the 3-Way Directional Valve (IL) block dialog description.
- 2 Select a part from the drop-down menu and click **Update block with selected part**.
- 3 If you change any parameter settings after loading a parameterization, you can check your changes by clicking **Compare block settings with selected part**. Any difference in settings between the block and pre-defined parameterization will display in the MATLAB command window.

Note that it is not possible to set different values for the same orifice for both positive and negative displacement of the control member. Additionally, the opening area is mirrored around the neutral position.

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**Note** Predefined parameterizations of Simscape components use available data sources for supplying parameter values. Engineering judgement and simplifying assumptions are used to fill in for missing data. As a result, deviations between simulated and actual physical behavior should be expected. To ensure requisite accuracy, you should validate simulated behavior against experimental data and refine component models as necessary.

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### Assumptions

- Fluid inertia is ignored.
- Spool loading due to inertial, spring, and other forces is ignored.
- All valve orifices are assumed to be identical in size unless otherwise specified.

### Ports

#### Conserving

##### A — Liquid port

isothermal liquid

Exit point of the valve.

**P – Liquid port**

isothermal liquid

Entry point to the valve.

**T – Liquid port**

isothermal liquid

Entry or exit point to the valve.

**Input****S – Control member displacement, m**

physical signal

Spool position displacement in m, received as a physical signal. For flow paths that open in the positive spool position, a positive signal opens the orifice. For flow paths that open in the negative spool position, a negative signal opens the orifice.

**Tr – External fault trigger**

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

**Dependencies**

This port is visible when **Enable faults** is set to On and **Fault trigger** is set to External.

**Parameters****Model Parameterization****Positive spool position open connections – Flow paths open when the spool is in a positive position**

P-T only (default) | All closed | P-A, A-T, and P-T | P-A only | A-T only

Flow paths open when the spool is in a positive position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Negative spool position open connections – Flow paths open when the spool moves in the negative direction**

P-A only (default) | All closed | P-A, A-T, and P-T | A-T only | P-T only

Flow paths open when the spool moves in the negative direction. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Area characteristics – Flow equations for orifices**

Identical for all flow paths (default) | Different for each flow path

Applies uniform or individual flow equations for the valve orifice area. **Identical for all flow paths** uses the same orifice and spool geometries, flow rates, pressure, and area vectors for all valve orifices. When using **Different for each flow path**, different spool offsets and tabulated data are assigned to the orifices between ports **P** and **A**, ports **A** and **T**, and ports **P** and **T**. In both cases,

ports **A**, **P**, and **T** have the same cross-sectional areas, discharge coefficients, and Reynolds numbers. The same **Orifice parameterization** is also applied to all flow paths.

#### **Orifice parameterization – Method of calculating opening area**

Linear area vs. spool travel (default) | Tabulated data - Area vs. spool travel |  
Tabulated data - volumetric flow rate vs. spool travel and pressure drop

Method of calculating the valve opening area. In the tabulated data parameterizations, you can provide your own valve area and spool travel data for nonlinear valve opening profiles, or you can provide data in terms of volumetric flow rate, spool travel, and pressure drop over the flow path.

#### **Spool travel between closed and open orifice – Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths.

#### **Maximum orifice area – Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area during operation of valve.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths.

#### **Cross-sectional area at ports A, P and T – Area at valve entry or exit**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A**, **P**, and **T**. These areas are used in the pressure-flow rate equation that determines volumetric flow rate through the valve.

#### **Leakage area – Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in its fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to `Linear - area vs. spool travel`.

#### **Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

#### **Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

**Pressure recovery – Whether to account for pressure increase in area expansions**

On (default) | Off

Select to account for pressure increase when fluid flows from a region of a smaller cross-sectional area to a region of larger cross-sectional area.

**Spool travel vector – Vector of valve opening distance**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to `Tabulated data - Area vs. spool travel`.

**Orifice area vector – Vector of valve opening areas**[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **Spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Opening parameterization** to `Tabulated data - Area vs. spool travel`.

**Spool travel vector, ds – Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to `Volumetric flow rate vs. spool travel and pressure drop`.

**Pressure drop vector, dp – Vector of valve pressure drop values**

[.3, .5, .7] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector,  $s$**  parameter for the 3-D dependent **Volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop.

#### Volumetric flow rate table, $q(ds,dp)$ – Array of volumetric flow rates

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Spool travel vector,  $ds$**  parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### P-A Orifice

##### Spool position at maximum P-A orifice area – Spool offset at maximum area between ports P and A

2.5e-3 m (default) | scalar

Initial orifice opening distance between ports **P** and **A**. The default represents an underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.

##### P-A spool travel between closed and open orifice – Maximum stroke for the spool between ports P and A

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **P** and **A**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path.

**P-A maximum orifice area — Maximum area between ports P and A**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice between ports **P** and **A** in its fully open position.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Linear - area vs. spool travel.

**P-A orifice spool travel vector — Vector of valve opening distance**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-A orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**P-A orifice area vector — Vector of valve opening areas**

[ $1e-09$ ,  $2.0352e-07$ ,  $4.0736e-05$ , .00011438, .00034356]  $\text{m}^2$  (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-A orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

**P-A orifice spool travel vector, ds — Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-A orifice pressure drop vector, dp** parameter for the 3-D dependent **P-A orifice volumetric flow rate table, q(s,dp)** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**P-A orifice pressure drop vector, dp — Vector of pressure drop values over the valve**

[.3, .5, .7] MPa (default) | 1-by-n vector



Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-A orifice spool travel vector, s** parameter for the 3-D dependent **P-A orifice volumetric flow rate table, q(s,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **P-A orifice volumetric flow rate table, q(ds,dp) – Vector of valve volumetric flow rates**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **P-A orifice pressure drop vector, dp** parameter.
- *N* is the number of elements in the **P-A orifice spool travel vector, s** parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **A-T Orifice**

#### **Spool position at maximum A-T orifice area – Spool offset at maximum area between ports A and T**

5e-3 m (default) | scalar

Initial orifice opening distance between ports **A** and **T**. The default represents an underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.

#### **A-T spool travel between closed and open orifice – Maximum stroke for the spool between ports A and T**

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **A** and **T**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set **Area characteristics** type to Different for each flow path.

**A-T maximum orifice area — Maximum area between ports A and T**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice between ports **A** and **T** in its fully open position.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Linear - area vs. spool travel.

**A-T orifice spool travel vector — Vector of valve opening distances**

$[0, .002, .004, .007, .017] \text{ m}$  (default) | 1-by- $n$  vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**A-T orifice area vector — Vector of valve opening areas**

$[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] \text{ m}^2$  (default) | 1-by- $n$  vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **A-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

**A-T orifice spool travel vector, ds — Vector of valve opening distances**

$[0, .002, .004, .007, .017] \text{ m}$  (default) | 1-by- $n$  vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **A-T orifice pressure drop vector, dp** parameter for the 3-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**A-T orifice pressure drop vector, dp — Vector of pressure drop values over the valve**

$[.3, .5, .7] \text{ MPa}$  (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-T orifice spool travel vector, s** parameter for the 3-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **A-T orifice volumetric flow rate table, q(ds,dp) — Vector of volumetric flow rate for tabular parameterization - different flow paths**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **A-T orifice pressure drop vector, dp** parameter.
- *N* is the number of elements in the **A-T orifice spool travel vector, s** parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### **P-T Orifice**

#### **Spool position at maximum P-T orifice area — Spool offset at maximum area between ports P and T**

5e-3 m (default) | scalar

Initial orifice opening distance between ports **P** and **T**. The default represents an underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.

#### **P-T spool travel between closed and open orifice — Maximum stroke for the spool between ports P and T**

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **P** and **T**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set **Area characteristics** type to Different for each flow path.

**P-T maximum orifice area — Maximum area between ports P and T**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice between ports **P** and **T** in its fully open position.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Linear - area vs. spool travel.

**P-T orifice spool travel vector — Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**P-T orifice area vector — Vector of valve opening areas**

[ $1e-09$ ,  $2.0352e-07$ ,  $4.0736e-05$ , .00011438, .00034356]  $\text{m}^2$  (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

**P-T orifice spool travel vector, ds — Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector, dp** parameter for the 3-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**P-T orifice pressure drop vector, dp — Vector of pressure drop values over the valve**

[.3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-T orifice spool travel vector, ds** parameter for the 3-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### P-T orifice volumetric flow rate table, q(ds,dp) – Vector of volumetric flow rate for tabular parameterization - different flow paths

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) | M-by-N matrix

M-by-N matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. M and N are the sizes of the corresponding vectors:

- M is the number of elements in the **P-T orifice pressure drop vector, dp** parameter.
- N is the number of elements in the **P-T orifice spool travel vector, ds** parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### Faults

##### Enable faults – Fault option

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Spool position when faulted** parameter.

##### Spool position when faulted – Set faulted characteristics

Positive (default) | Negative | Maintain last value

Sets the faulted valve spool position. You can choose for the valve to seize when the spool is in the positive position, negative position, or at the position when faulting is triggered.

#### Dependencies

To enable this parameter, set **Enable faults** to On.

##### Fault trigger – External trigger option

Off (default) | Fault when Tr >= 0.5

Whether a fault trigger occurs due to an external event or at a specified time.

When set to External, port **Tr** is enabled. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.

When set to **Temporal**, when the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to **On**.

**Simulation time for fault event — Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to **On** and **Fault trigger** to **Temporal**.

## Version History

Introduced in R2020a

### Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

4-Way 3-Position Directional Valve (IL) | 2-Way Directional Valve (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure-Reducing 3-Way Valve (IL) | Orifice (IL)

**Topics**

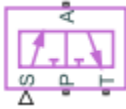
“Modeling Valves in Simscape Fluids”

“Building a Custom Valve”

## 3-Way Directional Valve (G)

Controlled valve with three ports in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Directional Control Valves

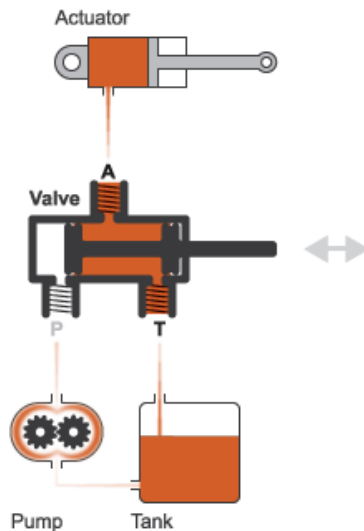


### Description

The 3-Way Directional Valve (G) block represents a valve with three gas ports (**P**, **A**, and **T**) and two flow paths between **P-A** and **A-T**. The paths each run through an orifice of variable width. The input signal specified at port **S** controls the position of the spool. The valve closes when the spool covers the orifice opening.

In a representative system, the **P** port connects to the pump, the **T** port connects to the tank, and the **A** port connects to a single-acting actuator. Opening the **P-A** flow path, while closing **A-T**, allows the pump to pressurize the actuator. Opening the **A-T** flow path, while closing **P-A**, allows the tank to absorb the excess pressure from the actuator, freeing the shaft to translate in reverse.

This image shows a common use for a three-way directional valve in a physical system:



The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

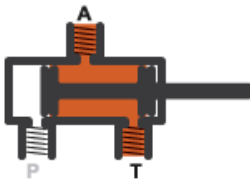
## Valve Positions

The valve is continuously variable and it shifts smoothly between one normal and two working positions.

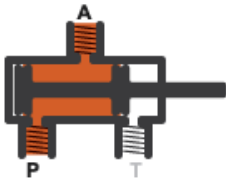
When the instantaneous displacement of the spool at port **S** is zero, the valve reverts to the normal position where it is no longer operating. Unless the lands of the spool are at an offset to their orifices, the valve is fully closed.

The working positions are the positions the valve moves to when the spool is maximally displaced, in either positive or negative direction, from the normal position. One orifice will then generally be closed and the other open to full capacity. Image **I** shows a valve where the displacement is in the negative direction, the **P-A** orifice is closed, and the **A-T** orifice is open. Image **II** shows a valve where the displacement is in the positive direction, the **P-A** orifice is open, and the **A-T** orifice is closed.

I.



II.



The spool displacement that puts the valve in its working position depends on the offsets of the lands on the spool. The parameters in the **Valve Opening Fraction Offsets** section specify the block constants for the spool displacements of the ports.

## Orifice Opening Fractions

Between valve positions, the opening of an orifice depends on where the land of the spool is, relative to the rim. This distance is the orifice opening, and the block normalizes this distance so that its value is a fraction of the maximum distance at which the orifice is fully open. The normalized variable is the orifice opening fraction.

The orifice opening fractions range from -1 when the valve is in the position shown in image **I** to +1 when the valve is in the position shown in image **II**.

The block calculates the opening fractions from the spool displacement and opening fraction offset. The displacement and offset are unitless fractions of the maximum land-orifice distance.

The opening fraction of the **P-A** orifice is:

$$h_{PA} = H_{PA} + x.$$



The opening fraction of the **A-T** orifice is:

$$h_{\text{AT}} = H_{\text{AT}} - \chi.$$

In both equations:

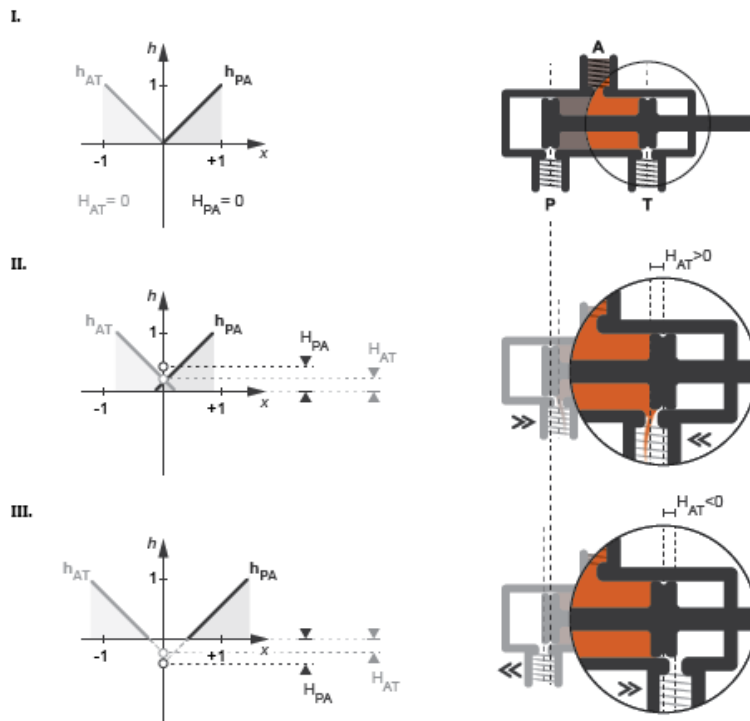
- $h$  is the opening fraction of the orifice specified by the subscript **P-A** or **A-T**. If the calculation returns a value outside of the range  $0 - 1$ , the block uses the nearest limit.
- $H$  is the opening fraction offset for the orifice. The parameters in the **Valve Opening Fraction Offsets** section specify the opening fraction offsets. To allow for unusual valve configurations, the block imposes no limit on their values, although generally these will fall between  $-1$  and  $+1$ .
- $\chi$  is the normalized instantaneous displacement of the spool, specified by a physical signal at port **S**. To compensate for extreme opening fraction offsets, there is no limit on the signal value. The value is typically between  $-1$  and  $+1$ .

### Opening Fraction Offsets

By default, the valve is fully closed when its control displacement is zero. In this state, the valve is zero-lapped.

You can offset the lands of the spool to model an underlapped or overlapped valve. Underlapped valves are partially open in the normal position. Overlapped valves are fully closed slightly beyond the normal position. The figure shows how the orifice opening fractions vary with the instantaneous spool displacement:

- **Image I:** A zero-lapped valve. The opening fraction offsets are both zero. When the valve is in the normal position, the lands of the spool completely cover both orifices.
- **Image II:** An underlapped valve. The opening fraction offsets are both positive. When the valve is in the normal position, the lands of the spool partially cover both orifices.
- **Image III:** An overlapped valve. The opening fraction offsets are both negative. The lands of the spool completely cover both orifices not only in the normal position but over a small region of spool displacements around it.



### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

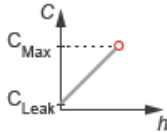
- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*. [1]
- **Orifice area** — The size of the flow restriction determines the block parameterization. [4]

### Opening Characteristics

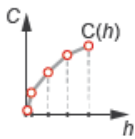
The flow characteristic relates the opening of the valve to the input that produces it, which is often the spool travel. The block expresses the opening as a sonic conductance, flow coefficient, or restriction area, depending on the setting of the **Valve parametrization** parameter. The control input is the orifice opening fraction, a function of the spool displacement specified at port **S**.

The flow characteristic is normally given at steady state, with the inlet at a constant, carefully controlled pressure. The flow characteristic depends only on the valve and can be linear or nonlinear. To capture the flow characteristics, use the **Opening characteristic** parameter:

- **Linear** — The measure of flow capacity is a linear function of the orifice opening fraction. As the opening fraction rises from 0 to 1, the measure of flow capacity scales from the specified minimum to the specified maximum.



- **Tabulated** — The measure of flow capacity is a general function, which can be linear or nonlinear, of the orifice opening fraction. The function is specified in tabulated form, with the independent variable specified by the **Opening fraction vector**



### Numerical Smoothing

When the **Opening characteristic** parameter is Linear, and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the orifice opening fraction. Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Leakage Flow

The leakage flow ensures that no section of a fluid network becomes isolated. Isolated fluid sections can reduce the numerical robustness of the model, slow the rate of simulation and, in some cases, cause the simulation to fail. The **Leakage flow fraction** parameter represents the leakage flow area in the block as a small number greater than zero.

### Composite Structure

This block is a composite component comprising two instances of the Orifice (G) block, one connected between ports **P** and **A** and a second block between **A** and **T**. Refer to the Orifice (G) block for more detail on the valve parameterizations and block calculations.

### Assumptions and Limitations

- The **Sonic** conductance setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice** area parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Input

#### **S – Valve control signal, unitless**

physical signal

Instantaneous displacement of the control member against its normal unactuated position, specified as a physical signal. The block normalizes the displacement against the maximum position of the control member that required to open the orifice fully. The signal is unitless and its instantaneous value is typically in the range between -1 and +1.

### Conserving

#### **A – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **P – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **T – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

## Parameters

### **Valve parameterization – Parameterization used to specify flow characteristics of orifice**

`Cv flow coefficient (default)` | `Kv flow coefficient` | `Sonic conductance` | `Orifice area`

Method to calculate the mass flow rate.

- `Cv flow coefficient` – The flow coefficient  $C_v$  determines the block parameterization.
- `Kv flow coefficient` – The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- `Sonic conductance` – The sonic conductance of the resistive element at steady state determines the block parameterization.
- `Orifice area` – The size of the flow restriction determines the block parametrization.

### **Opening characteristic – Method to calculate the opening characteristics of the valve**

`Linear (default)` | `Tabulated`

Method the block uses to calculate the opening area of the valve. The linear setting treats the opening area as a linear function of the orifice opening fraction. The tabulated setting allows for a general, nonlinear relationship you can specify in tabulated form.

**Opening fraction vector – Control signal values at which to specify tabulated parameter data**

0 : 0.2 : 1 (default) | vector of positive numbers

Vector of control signal values at which to specify the chosen measure of flow capacity: **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector**. The control signal is between 0 and 1, with each value corresponding to an opening fraction of the resistive element. The greater the value, the greater the opening and easier the flow.

The opening fractions must increase monotonically across the vector from left to right. The size of this vector must be the same as the **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector** parameter.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Tabulated.

**Maximum Cv flow coefficient – Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Linear.

**xT pressure differential ratio factor at choked flow – Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Leakage flow fraction – Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Cv flow coefficient vector – Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum Kv flow coefficient – Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector – Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers

Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum sonic conductance – Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**, and **Opening characteristic** to **Linear**.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**, and **Opening characteristic** to **Linear**.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**ISO reference density — ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12] 1/(bar\*s) (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**, and **Opening characteristic** to **Tabulated**.

**Critical pressure ratio vector – Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Maximum orifice area – Flow area corresponding to maximally open component**1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Linear`.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Orifice area vector – Vector of orifice opening area values**[1e-10, 2e-05, 4e-05, 6e-05, 8e-05, .0001] m<sup>2</sup> (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Tabulated`.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A, P, and T – Area normal to the flow path at the valve ports**0.01 m<sup>2</sup> (default) | positive scalar in units of area



Area normal to the flow path at the valve ports. The ports are assumed to be of the same size. The flow area specified here should ideally match those of the inlets of adjoining components.

### Valve Opening Fraction Offsets

#### Between Ports P and A — Opening fraction offset for the P-A orifice

0 (default) | unitless scalar

Opening fraction of the **P-A** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **P-A**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

#### Between Ports A and T — Opening fraction offset for the A-T orifice

0 (default) | unitless scalar

Opening fraction of the **A-T** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **A-T**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

## Version History

### Introduced in R2018b

#### Model gas systems using improved flow computations

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Orifice (G) | 2-Way Directional Valve (G) | 4-Way 3-Position Directional Valve (G)

## 3-Way Directional Valve (TL)

3-position directional valve in a thermal liquid network

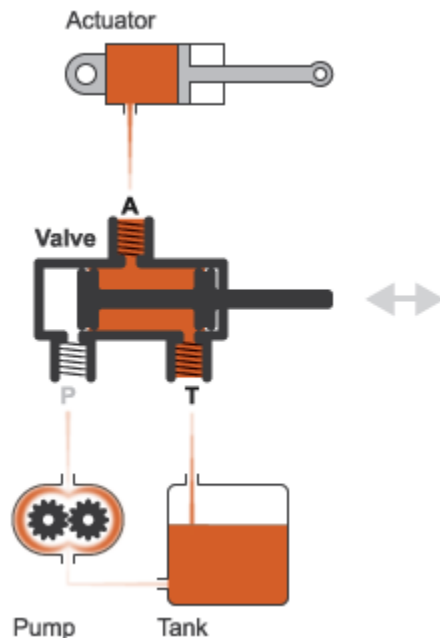
**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Directional Control Valves



### Description

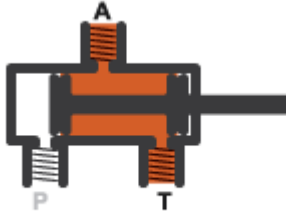
The 3-Way Directional Valve (TL) block represents a valve with three openings in a thermal liquid network, typically between an actuator, pump, and tank. The valve operation is controlled by a single spool displaced according to the signal at port **S**. You can set the baseline configuration of your valve by specifying the orifices that are open when the spool moves in the positive direction and negative directions in the **Positive spool position open connections** and **Negative spool position open connections** parameters, respectively.

You can set the model for valve opening in the **Orifice parameterization** parameter as a linear relationship or function of user-provided data, which can be applied to one or all flow paths in the valve.

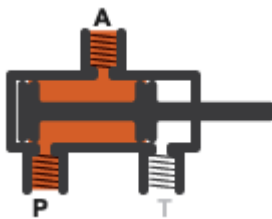


### Example Valve Configuration

In this configuration, **Positive spool position open connections** is set to A-T only. When the signal at port **S** moves the spool to a positive position, the path between ports **A** and **T** is open to flow. The paths between ports **P** and **A** and between ports **P** and **T** are closed:



In this configuration, **Negative spool position open connections** is set to P-A only. When the signal at port **S** moves the spool to a negative position, the path between ports **P** and **A** is open to flow and the paths between ports **T** and **A** and between ports **P** and **T** are closed:



You can open the path between ports **P** and **T** by setting either **Positive spool position open connections** or **Negative spool position open connections** to P-T only or P-A, A-T, and P-T.

A flow path can be open in either the positive or negative spool positions, but not both.

### Valve Orifice Parameterizations

The **Orifice parameterization** sets the method for calculating the valve open area. The calculations are based either on the orifice parameters or tabulated data sets specified in the **Model Parameterization** tab. The block uses the same data for all flow paths if **Area characteristics** is set to **Identical for all flow paths**; otherwise, individual values are applied in the **Different for all flow paths** setting. The orifice parameterizations are:

- Linear - area vs. spool travel

The opening area is a linear function of the spool travel distance and the signal received at port **S**:

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where:

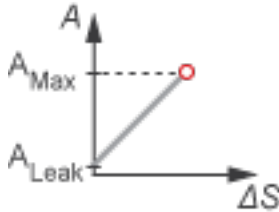
- $A_{max}$  is the **Maximum orifice area**.
- $A_{leak}$  is the **Leakage area**.
- $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.
- $\Delta S$  is the spool travel distance. For flow paths that are open in the positive position:

$$\Delta S = S_{orifice\_max} - \Delta S_{max} + S,$$

and for flow paths that are open in the negative position:

$$\Delta S = S_{orifice\_max} + \Delta S_{max} - S,$$

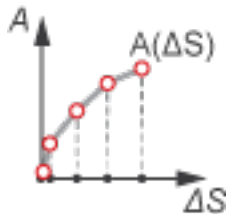
where  $S_{orifice\_max}$  is the **Spool position at maximum orifice area**.



When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

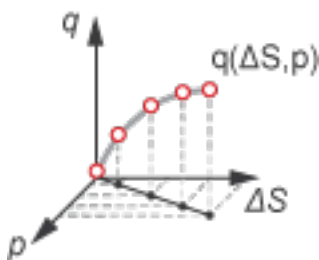
- Tabulated data - Area vs. spool travel

Provide spool travel vectors for your system or for individual flow paths between ports **P** and **A**, **A** and **T**, and **P** and **T**. This data will be used to calculate the relationship between the orifice opening area and spool travel distance. Interpolation is used to determine the opening area between given data points.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Opening area vector**, respectively.

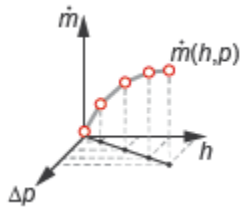


- Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Provide spool travel and pressure drop vectors. The volumetric flow rate is calculated based on the relationship between pressure change and the spool travel distance. Interpolation is used to determine flow rate between given data points. The mass flow rate is the product of the volumetric flow rate and the local density.



When you set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop the block calculates the mass flow rate directly from the control member position and the pressure drop across the valve. The relationship between the three variables can be nonlinear and it is given by the tabulated data in the **Spool travel vector**, **ds**, **Pressure drop vector**, **dp**, and **Mass flow rate table**, **mdot(ds,dp)** parameters.



### Visualize Orifice Openings

To visualize spool offsets and displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the orifices selected in the **Valve Configuration** settings. The parameterization selection sets the axes, which are either:

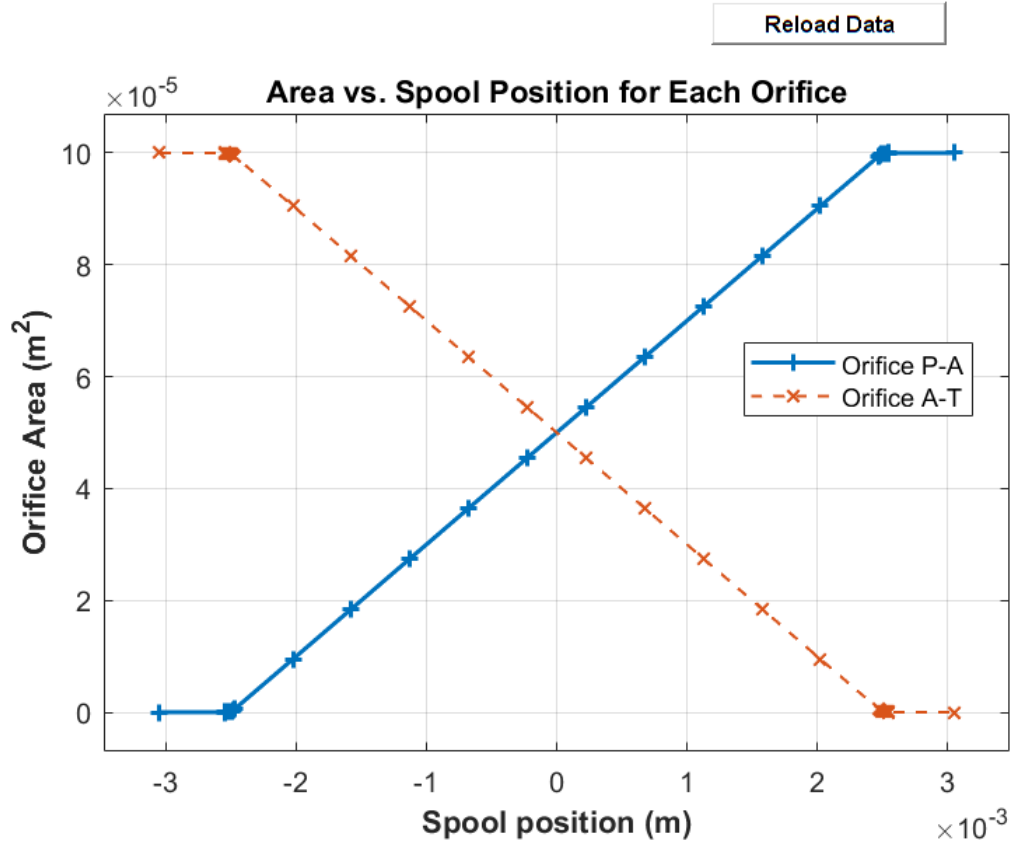
- Orifice area versus spool position
- Volumetric flow rate versus spool position, queried at a specific pressure differential
- Mass flow rate versus spool position for the reference inflow temperature and reference inflow pressure, queried at a specific pressure differential

To update the data after changing the block parameters, click **Reload Data** on the figure window.

This image shows an example valve configuration. In the **Valve Configuration** settings:

- **Positive spool position open connections** is P-A only.
- **Negative spool position open connections** is A-T only.

All other spool positions are at the default values.



### Assumptions

- Fluid inertia is ignored.
- Spool loading due to inertial, spring, and other forces is ignored.
- All valve orifices are assumed to be identical in size unless otherwise specified.

### Ports

#### Input

##### **S – Control member displacement**

physical signal

Displacement of the valve control member, in m. This is equivalent to the spool position.

#### Conserving

##### **P – Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to a fluid supply line.

**T – Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to a fluid return line.

**A – Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to an actuation line.

**Parameters****Model Parameterization****Positive spool position open connections – Flow paths open when the spool is in a positive position**

P-A only (default) | All closed | P-A, A-T, and P-T | P-T only | A-T only

Flow paths open when the spool is in a positive position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Negative spool position open connections – Flow paths open when the spool moves in the negative direction**

A-T only (default) | All closed | P-A, A-T, and P-T | P-A only | P-T only

Flow paths open when the spool moves in the negative direction. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Area characteristics – Flow equations for orifices**

Identical for all flow paths (default) | Different for each flow path

Applies uniform or individual flow equations for the valve orifice area. **Identical for all flow paths** uses the same orifice and spool geometries, flow rates, pressure, and area vectors for all valve orifices. When using **Different for each flow path**, the spool offsets and tabulated data are assigned to the orifices between ports **P** and **A**, ports **A** and **T**, and ports **P** and **T**. In both cases, ports **A**, **P**, and **T** have the same cross-sectional areas, discharge coefficients, and Reynolds numbers. The same **Orifice parameterization** is also applied to all flow paths.

**Orifice parameterization – Method of calculating opening area**Linear area vs. spool travel (default) | Tabulated data - Area vs. spool travel |  
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop  
Tabulated data - Mass flow rate vs. spool travel and pressure drop

Method of calculating the valve opening area. In the tabulated data parameterizations, you can provide your own valve area and spool travel data for nonlinear valve opening profiles, or you can provide data in terms of volumetric flow rate, spool travel, and pressure drop over the flow path. The thermal liquid domain allows you to parameterize the orifice using tabulated mass flow rate data.

**Spool travel between closed and open orifice – Maximum spool stroke**

5e-3 m (default) | positive scalar



Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths.

#### Maximum orifice area — Maximum orifice opening area

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area during operation of valve.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths.

#### Spool travel vector — Vector of valve opening distance

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

#### Orifice area vector — Vector of valve opening areas

[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **Spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Opening parameterization** to Tabulated data - Area vs. spool travel.

#### Leakage area — Gap area when in fully closed position

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in its fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - area vs. spool travel.

#### Smoothing factor — Numerical smoothing factor

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

### Spool travel vector, **ds** — Vector of valve opening distances

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

### Pressure drop vector, **dp** — Vector of valve pressure drop values

[.3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, s** parameter for the 3-D dependent **Volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

### Volumetric flow rate table, **q(ds,dp)** — Array of volumetric flow rates

1e-3 \* [1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Spool travel vector, ds** parameter.
- *N* is the number of elements in the **Pressure drop vector, dp** parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

### Reference inflow temperature — Temperature at which pressure-drop data is specified

293.15 K (default) | positive scalar

Temperature at which the tabulated pressure-drop data is specified.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Reference inflow pressure — Pressure at which pressure-drop tabulated data is specified**

0.101325 MPa (default) | positive scalar

Pressure at which the tabulated pressure-drop data is specified. The block uses this parameter to calculate a third reference parameter, the reference density. The reference that it uses to scale the tabulated pressure drop data for pressures and temperatures deviating from the reference conditions.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Mass flow rate table,  $\dot{m}(ds, dp)$  — Mass flow rate**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default) | M-by-N matrix

Mass flow rate for  $M$  given control member positions and  $N$  given pressure drops over the orifice. The control member position represents a spool or other mechanism that controls the opening area.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Discharge coefficient — Discharge coefficient**

0.7 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Pressure recovery — Whether to account for pressure increase in area expansions**

On (default) | Off

Select to account for pressure increase when fluid flows from a region of a smaller cross-sectional area to a region of larger cross-sectional area.

**Cross-sectional area at ports A, P and T — Area at valve entry or exit**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A**, **P**, and **T**. These areas are used in the pressure-flow rate equation that determines volumetric flow rate through the valve.

## P-A Orifice

### Spool position at maximum P-A orifice area — Spool offset at maximum area between ports P and A

2.5e-3 m (default) | scalar

Initial orifice opening distance between ports **P** and **A**. The default represents a underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.

### P-A spool travel between closed and open orifice — Maximum stroke for the spool between ports P and A

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **P** and **A**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set **Area characteristics** to **Different** for each flow path.

### P-A maximum orifice area — Maximum area between ports P and A

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice between ports **P** and **A** in its fully open position.

#### Dependencies

To enable this parameter, set **Area characteristics** to **Different** for each flow path and **Orifice parameterization** to **Linear - area vs. spool travel**.

### P-A orifice spool travel vector — Vector of valve opening distance

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-A orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to **Different** for each flow path and **Orifice parameterization** to **Tabulated data - Area vs. spool travel**.

### P-A orifice area vector — Vector of valve opening areas

[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-A orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

#### P-A orifice spool travel vector, $ds$ – Vector of valve opening distances

[0, .002, .004, .007, .017] m (default) | 1-by- $n$  vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-A orifice pressure drop vector,  $dp$**  parameter for the 3-D dependent **P-A orifice volumetric flow rate table,  $q(s,dp)$**  or **Mass flow rate table,  $mdot(ds,dp)$**  parameters. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### P-A orifice pressure drop vector, $dp$ – Vector of pressure drop values over the valve

[.3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-A orifice spool travel vector,  $s$**  parameter for the 3-D dependent **P-A orifice volumetric flow rate table,  $q(s,dp)$**  or **Mass flow rate table,  $mdot(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### P-A orifice volumetric flow rate table, $q(ds,dp)$ – Vector of valve volumetric flow rates

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **P-A orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **P-A orifice spool travel vector,  $s$**  parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**P-A orifice mass flow rate table,  $\dot{m}(ds, dp)$  — Vector of valve mass flow rates**  
 [1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **P-A orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **P-A orifice spool travel vector,  $s$**  parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### A-T Orifice

**Spool position at maximum A-T orifice area — Spool offset at maximum area between ports A and T**

-2.5e-3 m (default) | scalar

Initial orifice opening distance between ports **A** and **T**. The default represents a underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.

**A-T spool travel between closed and open orifice — Maximum stroke for the spool between ports A and T**

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **A** and **T**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set **Area characteristics** type to Different for each flow path.

**A-T maximum orifice area — Maximum area between ports A and T**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice between ports **A** and **T** in its fully open position.

#### Dependencies

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Linear - area vs. spool travel.

**A-T orifice spool travel vector – Vector of valve opening distances**[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**A-T orifice area vector – Vector of valve opening areas**[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **A-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

**A-T orifice spool travel vector, ds – Vector of valve opening distances**[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **A-T orifice pressure drop vector, dp** parameter for the 3-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**A-T orifice pressure drop vector, dp – Vector of pressure drop values over the valve**[.3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-T orifice spool travel vector, s** parameter for the 3-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**A-T orifice volumetric flow rate table,  $q(ds,dp)$  – Vector of volumetric flow rate for tabular parameterization - different flow paths**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **A-T orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **A-T orifice spool travel vector,  $s$**  parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**A-T orifice mass flow rate table,  $\dot{m}(ds,dp)$  – Vector of mass flow rate for tabular parameterization - different flow paths**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **A-T orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **A-T orifice spool travel vector,  $s$**  parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**P-T Orifice****Spool position at maximum P-T orifice area – Spool offset at maximum area between ports P and T**

2.5e-3 m (default) | scalar

Initial orifice opening distance between ports **P** and **T**. The default represents a underlapped system.

- If the magnitude of **Spool position at maximum orifice area** is less than the value of **Spool travel between closed and open orifice**, the orifice is underlapped, or partially open when the spool position equals 0 m.
- If the magnitude of **Spool position at maximum orifice area** is greater than the value of **Spool travel between closed and open orifice**, the orifice is overlapped. This means the valve remains closed over a range of spool positions.
- If the magnitude of **Spool position at maximum orifice area** is equal to the value of **Spool travel between closed and open orifice**, the orifice is zero-lapped. This means the valve is closed when the spool position equals 0 and begins to open as soon as the spool position changes.



**P-T spool travel between closed and open orifice – Maximum stroke for the spool between ports P and T**

0.005 m (default) | positive scalar

Maximum distance of spool travel for the orifice between ports **P** and **T**. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set **Area characteristics** type to Different for each flow path.

**P-T maximum orifice area – Maximum area between ports P and T**1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice between ports **P** and **T** in its fully open position.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Linear - area vs. spool travel.

**P-T orifice spool travel vector – Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**P-T orifice area vector – Vector of valve opening areas**[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Opening parameterization** to Tabulated data - Area vs. spool travel.

**P-T orifice spool travel vector, ds – Vector of valve opening distances**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member travel distances for tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector, dp** parameter for the 3-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**P-T orifice pressure drop vector,  $dp$**  — Vector of pressure drop values over the valve  
[.3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-T orifice spool travel vector,  $ds$**  parameter for the 3-D dependent **P-T orifice volumetric flow rate table,  $q(ds,dp)$**  or **Mass flow rate table,  $mdot(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**P-T orifice volumetric flow rate table,  $q(ds,dp)$**  — Vector of volumetric flow rate for tabular parameterization - different flow paths  
[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **P-T orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **P-T orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**P-T orifice mass flow rate table,  $mdot(ds,dp)$**  — Vector of mass flow rate for tabular parameterization - different flow paths  
[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default)

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **P-T orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **P-T orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

## Version History

Introduced in R2016a

### Right-click blocks to view opening characteristic plots

You can view the plot of the area or volumetric flow rate with respect to spool position for each orifice by right-clicking the block and selecting **Fluids > Plot Valve Characteristics**.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Orifice (TL) | 2-Way Directional Valve (TL) | 4-Way 3-Position Directional Valve (TL) | Check Valve (TL)

## 3-Zone Pipe (2P)

Conduit for the transport of a phase-changing fluid with heat transfer

**Library:** Simscape / Fluids / Two-Phase Fluid / Pipes & Fittings



### Description

The 3-Zone Pipe (2P) block models a pipe with a phase-changing fluid. Each fluid phase is called a *zone*, which is a fractional value between 0 and 1. Zones do not mix. The block uses a boundary-following model to track the sub-cooled liquid (L), vapor-liquid mixture (M), and super-heated vapor (V) in three zones. The relative amount of space a zone occupies in the system is called a *zone length fraction* within the system.

Port **H** is a thermal port that represents the environmental temperature. The rate of heat transfer between the fluid and the environment depends on the fluid phase of each zone. The pipe wall is modeled within the block and the pipe wall temperature in each zone may be different. The pressure and temperature are influenced by fluid dynamic compressibility and the fluid zone thermal capacity.

### Heat Transfer Between the Fluid and the Wall

The convective heat transfer coefficient between the fluid and the wall,  $\alpha_F$ , varies per zone according to the Nusselt number:

$$\alpha_F = \frac{Nu k}{D_H}$$

where:

- Nu is the zone Nusselt number.
- $k$  the average fluid thermal conductivity.
- $D_H$  is the pipe **Hydraulic diameter**, the equivalent diameter of a non-circular pipe.

The Nusselt number used in the heat transfer coefficient is the greater of the turbulent- and laminar-flow Nusselt numbers.

For turbulent flows in the subcooled liquid or superheated vapor zones, the Nusselt number is calculated with the Gnielinski correlation:

$$Nu = \frac{\frac{f}{8}(Re-1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{1/2}(Pr^{2/3} - 1)}$$

where:

- Re is the zone average Reynolds number.
- Pr is the zone average Prandtl number.
- $f$  is the Darcy friction factor, calculated from the Haaland correlation:

$$\frac{1}{\sqrt{f}} = -1.8 \log \left[ \left( \frac{\varepsilon}{3.7 D_H} \right)^{1.11} + \frac{6.9}{Re} \right],$$

where  $\varepsilon$  is the wall **Internal surface absolute roughness**.

For turbulent flows in the liquid-vapor mixture zone, the Nusselt number is calculated with the Cavallini-Zecchin correlation:

$$Nu = \frac{a Re_{SL}^b Pr_{SL}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{Out} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{In} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) (x_{Out} - x_{In})}.$$

Where:

- $Re_{SL}$  is the Reynolds number of the saturated liquid.
- $Pr_{SL}$  is the Prandtl number of the saturated liquid.
- $\rho_{SL}$  is the density of the saturated liquid.
- $\rho_{SV}$  is the density of the saturated vapor.
- $a = 0.05$ ,  $b = 0.8$ , and  $c = 0.33$ .

When fins are modeled on the pipe internal surface, the heat transfer coefficient is:

$$\alpha_F = \frac{Nu k}{D_H} (1 + \eta_{Int} s_{Int}),$$

where:

- $\eta_{Int}$  is the **Internal fin efficiency**.
- $s_{Int}$  is the **Ratio of internal fins surface area to no-fin surface area**.

For laminar flows, the Nusselt number is set by the **Laminar flow Nusselt number** parameter.

#### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** parameter is Colburn equation, the block calculates the Nusselt number for the subcooled liquid and superheated vapor zones by using the empirical Colburn equation

$$Nu = a Re^b Pr^c,$$

where  $a$ ,  $b$ , and  $c$  are values in the **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in liquid zone** and **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in vapor zone** parameters.

The block calculates the Nusselt number for liquid-vapor mixture zones by using the Cavallini-Zecchin equation with the variables in the **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in mixture zone** parameter.

#### Specific Enthalpy

The heat transfer rate from the fluid is based on the change in specific enthalpy in each zone:

$$Q = \dot{m}_Q(\Delta h_L + \Delta h_M + \Delta h_V),$$

where  $\dot{m}_Q$  is the mass flow rate for heat transfer. It is the pipe inlet mass flow rate, either  $\dot{m}_A$  or  $\dot{m}_B$ , depending on the direction of fluid flow.

In the liquid and vapor zones, the change in specific enthalpy is defined as:

$$\Delta h = c_p(T_H - T_I) \left[ 1 - \exp\left(-\frac{zS_W}{\dot{m}_Q c_p (\alpha_F^{-1} + \alpha_E^{-1})}\right) \right],$$

where:

- $c_p$  is the specific heat of the liquid or vapor.
- $T_H$  is the environmental temperature.
- $T_I$  is the liquid inlet temperature.
- $z$  is the fluid zone length fraction.
- $\alpha_E$  is the heat transfer coefficient between the wall and the environment.
- $S_W$  is wall surface area:

$$S_W = \frac{4A}{D_H}L,$$

where:

- $A$  is the pipe **Cross-sectional area**.
- $L$  is the **Pipe length**.

Note that this wall surface area does not include fin area, which is defined in the **Ratio of external fins surface area to no-fin surface area** and **Ratio of internal fins surface area to no-fin surface area** parameters. Fins are set in proportion to the wall surface area. A value of 0 means there are no fins on the pipe wall.

In the liquid-vapor mixture zone, the change in specific enthalpy is calculated as:

$$\Delta h = (T_H - T_S) \frac{zS_W}{\dot{m}_Q (\alpha_F^{-1} + \alpha_E^{-1})},$$

where  $T_S$  is the fluid saturation temperature. It is assumed that the liquid-vapor mixture is always at this temperature.

### Heat Transfer Rate

The total heat transfer between the fluid and the pipe wall is the sum of the heat transfer in each fluid phase:

$$Q_F = Q_{F,L} + Q_{F,V} + Q_{F,M}.$$

The heat transfer rate between the fluid and the pipe in the liquid zone is:

$$Q_{F,L} = \dot{m}_Q c_{p,L} [T_{W,L} - \min(T_I, T_S)] \left[ 1 - \exp\left(-\frac{z_L S_W \alpha_L}{\dot{m}_Q c_{p,L}}\right) \right].$$

where  $T_{WL}$  is the temperature of the wall surrounding the liquid zone.

The heat transfer rate between the fluid and the pipe in the mixture zone is:

$$Q_{F,M} = (T_H - T_{\text{Sat}})z_M S_W \alpha_M.$$

The heat transfer rate between the fluid and the pipe in the vapor zone is:

$$Q_{F,V} = \dot{m}_Q c_{p,V} [T_{W,V} - \min(T_L, T_{\text{Sat}})] \left[ 1 - \exp\left(-\frac{z_V S_W \alpha_V}{\dot{m}_Q c_{p,V}}\right) \right],$$

where  $T_{W,V}$  is the temperature of the wall surrounding the vapor zone.

### Heat Transfer Between the Wall and the Environment

If the pipe wall has a finite thickness, the heat transfer coefficient between the wall and the environment,  $\alpha_E$ , is defined by:

$$\frac{1}{\alpha_E} = \frac{1}{\alpha_W} + \frac{1}{\alpha_{\text{Ext}}(1 + \eta_{\text{Ext}} s_{\text{Ext}})},$$

where  $\alpha_W$  is the heat transfer coefficient due to conduction through the wall:

$$\alpha_W = \frac{k_W}{D_H \ln\left(1 + \frac{t_W}{D_H}\right)},$$

and where:

- $k_W$  is the **Wall thermal conductivity**.
- $t_W$  is the **Wall thickness**.
- $\alpha_{\text{Ext}}$  is the **External environment heat transfer coefficient**.
- $\eta_{\text{Ext}}$  is the **External fin efficiency**.
- $s_{\text{Ext}}$  is the **Ratio of external fins surface area to no-fin surface area**.

If the wall does not have thermal mass, the heat transfer coefficient between the wall and environment equals the heat transfer coefficient of the environment,  $\alpha_{\text{Ext}}$ .

### Heat Transfer Rate

The heat transfer rate between each wall zone and the environment is:

$$Q_{H,\text{zone}} = (T_H - T_W)z S_W \alpha_E.$$

The total heat transfer between the wall and the environment is:

$$Q_H = Q_{H,L} + Q_{H,V} + Q_{H,M}.$$

### Governing Differential Equations

The heat transfer rate depends on the thermal mass of the wall,  $C_W$ :

$$C_W = c_{p,W} \rho_W S_W \left( t_W + \frac{t_W^2}{D_H} \right),$$

where:

- $c_{p,W}$  is the **Wall specific heat**.
- $\rho_W$  is the **Wall density**.

The governing equations for heat transfer between the fluid and the external environment are, for the liquid zone:

$$Q_{H,L} - Q_{F,L} = C_W \left[ z_L \frac{dT_{W,L}}{dt} + \max\left(\frac{dz_L}{dt}, 0\right) (T_{W,L} - T_{W,M}) \right],$$

for the mixture zone:

$$Q_{H,M} - Q_{F,M} = C_W \left[ z_M \frac{dT_{W,M}}{dt} + \min\left(\frac{dz_L}{dt}, 0\right) (T_{W,L} - T_{W,M}) + \min\left(\frac{dz_V}{dt}, 0\right) (T_{W,V} - T_{W,M}) \right],$$

and for the vapor zone:

$$Q_{H,V} - Q_{F,V} = C_W \left[ z_V \frac{dT_{W,V}}{dt} + \max\left(\frac{dz_V}{dt}, 0\right) (T_{W,V} - T_{W,M}) \right].$$

### Momentum Balance

The pressure differential over the pipe consists of two factors: changes in pressure due to changes in density, and changes in pressure due to friction at the pipe walls.

For turbulent flows, when the Reynolds number is above the **Turbulent flow lower Reynolds number limit**, pressure loss is calculated in terms of the Darcy friction factor. The pressure differential between port **A** and the internal node I is:

$$p_A - p_I = \left( \frac{1}{\rho_I} - \frac{1}{\rho_A^*} \right) \left( \frac{\dot{m}_A}{S} \right)^2 + \frac{f_A \dot{m}_A |\dot{m}_A| (L + L_{Add})}{2 \rho_I D_H S^2},$$

where:

- $\rho_I$  is the fluid density at internal node I.
- $\rho_A^*$  is the fluid density at port **A**. This is the same as  $\rho_A$  when the flow is steady-state; when the flow is transient, it is calculated from the fluid internal state with the adiabatic expression:

$$u_A^* + \frac{p_A}{\rho_A^*} + \frac{1}{2} \left( \frac{\dot{m}_A}{\rho_A^* S} \right)^2 = h + \frac{1}{2} \left( \frac{\dot{m}_A}{\rho S} \right)^2,$$

where:

- $h$  is the average specific enthalpy,  $h = h_L z_L + h_V z_V + h_M z_M$ .
- $\rho$  is the average density,  $\rho = \rho_L z_L + \rho_M z_M + \rho_V z_V$ .

This is due to the fact that heat transfer calculation takes place at the internal node I.

- $\dot{m}_A$  is the mass flow rate through port **A**.
- $L$  is the **Pipe length**.
- $L_{Add}$  is the **Aggregate equivalent length of local resistances**, which is the equivalent length of a tube that introduces the same amount of loss as the sum of the losses due to other local resistances.



Note that the Darcy friction factor is dependent on the Reynolds number, and is calculated at both ports.

The pressure differential between port **B** and internal node I is:

$$p_B - p_I = \left( \frac{1}{\rho_I} - \frac{1}{\rho_B^*} \right) \left( \frac{\dot{m}_B}{S} \right)^2 + \frac{f_B \dot{m}_B |\dot{m}_B| (L + L_{Add})}{2\rho_I D_H S^2}.$$

where:

- $\rho_B^*$  is the fluid density at port **B**. This is the same as  $\rho_B$  when the flow is steady-state; when the flow is transient, it is calculated from the fluid internal state with the adiabatic expression:

$$u_B^* + \frac{p_B}{\rho_B^*} + \frac{1}{2} \left( \frac{\dot{m}_B}{\rho_B^* S} \right)^2 = h + \frac{1}{2} \left( \frac{\dot{m}_B}{\rho S} \right)^2.$$

- $\dot{m}_B$  is the mass flow rate through port **B**.

For laminar flows, when the Reynolds number is below the **Laminar flow upper Reynolds number limit**, the pressure loss due to friction is calculated in terms of the **Laminar friction constant for Darcy friction factor**,  $\lambda$ . The pressure differential between port **A** and internal node I is:

$$p_A - p_I = \left( \frac{1}{\rho_I} - \frac{1}{\rho_A^*} \right) \left( \frac{\dot{m}_A}{S} \right)^2 + \frac{\lambda \mu \dot{m}_A (L + L_{Add})}{2\rho_I D_H^2 S},$$

where  $\mu$  is the average fluid dynamic viscosity:

$$\mu = \mu_L z_L + \mu_M z_M + \mu_V z_V.$$

The pressure differential between port **B** and internal node I is:

$$p_B - p_I = \left( \frac{1}{\rho_I} - \frac{1}{\rho_B^*} \right) \left( \frac{\dot{m}_B}{S} \right)^2 + \frac{\lambda \mu \dot{m}_B (L + L_{Add})}{2\rho_I D_H^2 S}.$$

For transitional flows, the pressure differential due to viscous friction is a smoothed blend between the values for laminar and turbulent pressure losses.

### Mass Balance

The total mass accumulation rate is defined as:

$$\frac{dM}{dt} = \dot{m}_A + \dot{m}_B,$$

where  $M$  is the total fluid mass in the pipe. In terms of fluid zones, the mass accumulation rate is a function of the change in density,  $\rho$ , with respect to pressure,  $p$ , and the fluid specific internal energy,  $u$ :

$$\frac{dM}{dt} = \left[ \left( \frac{\partial \rho}{\partial p} \right)_u \frac{dp}{dt} + \left( \frac{\partial \rho}{\partial u} \right)_p \frac{du_{out}}{dt} + \rho_L \frac{dz_L}{dt} + \rho_M \frac{dz_M}{dt} + \rho_V \frac{dz_V}{dt} \right] V,$$

where:

- $u_{out}$  is the specific internal energy after all heat transfer has occurred.
- $V$  is the total fluid volume, or the volume of the pipe.

### Energy Balance

The energy conservation equation is:

$$M \frac{du_{out}}{dt} + (\dot{m}_A + \dot{m}_B)u_{out} = \phi_A + \phi_B + Q_F,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.
- $Q_F$  is the heat transfer rate between the fluid and the wall.

### Assumptions and Limitations

- The pipe wall is perfectly rigid.
- The flow is fully developed. Friction losses and heat transfer do not include entrance effects.
- Fluid inertia is negligible.
- The effect of gravity is negligible.
- When the pressure is above the fluid critical pressure, large values of thermal fluid properties (such as Prandtl number, thermal conductivity, and specific heat) may not accurately reflect the heat exchange in the pipe.

## Ports

### Output

#### Z – Zone length fractions

physical signal

Vector with the length fractions of the liquid, mixed-phase, and vapor zones in the pipe.

### Conserving

#### A – Pipe opening

two-phase fluid

Opening through which the two-phase fluid flows into or out of the pipe. Ports **A** and **B** can each function as either inlet or outlet. Thermal conduction is allowed between the two-phase fluid ports and the fluid internal to the pipe (though its impact is typically relevant only at near zero flow rates).

#### B – Pipe opening

two-phase fluid

Opening through which the two-phase fluid flows into or out of the pipe. Ports **A** and **B** can each function as either inlet or outlet. Thermal conduction is allowed between the two-phase fluid ports and the fluid internal to the pipe (though its impact is typically relevant only at near zero flow rates).

**H — Pipe wall**

thermal

Thermal boundary condition at the outer surface of the pipe wall. Use this port to capture heat exchange of various kinds—for example, conductive, convective, or radiative—between the pipe wall and the environment. Heat exchange between the inner surface of the wall and the fluid is captured directly in the block.

**Parameters****Geometry****Pipe length — Distance between the ports of the pipe**

5 m (default) | positive scalar with units of length

Distance between the ports of the pipe. The liquid, two-phase, and vapor zones each comprise a fraction of this distance. The zone fractions can vary but their aggregate length, being the same as the distance of the pipe, is fixed.

**Cross-sectional area — Internal area normal to the direction of the flow**0.01 m<sup>2</sup> (default) | positive scalar with units of area

Internal area of the pipe normal to the direction of flow. The cross section of the pipe is assumed to be constant throughout its length.

**Hydraulic diameter — Diameter of a cylindrical pipe with the given cross-sectional area**

0.1 m (default) | positive scalar in units of length

Ratio of the opening area of a cross section of the pipe to the perimeter of that area. The pipe is not required to be cylindrical, and its cross-section have any shape. This parameter gives the diameter that a general cross section would have if it were circular.

**Viscous Friction****Aggregate equivalent length of local resistances — Minor pressure loss in the pipe expressed as a length**

1 m (default) | positive scalar in units of length

Combined length of all local resistances present in the pipe. Local resistances include bends, fittings, armatures, and pipe inlets and outlets. The effect of the local resistances is to increase the effective length of the pipe. This length is added to the geometrical pipe length for friction calculations.

**Internal surface absolute roughness — Average depth of surface defects on the internal surface of the pipe**

15e-6 m (default) | positive scalar in units of length

Average depth of all surface defects on the internal surface of the pipe. The surface defects affect the pressure loss across the pipe in the turbulent flow regime.

**Laminar flow upper Reynolds number limit — Reynolds number below which the flow is laminar**

2e+3 (default) | positive unitless scalar

Reynolds number above which the pipe flow begins to transition from laminar to turbulent. This value is the maximum Reynolds number corresponding to fully developed laminar flow.

**Turbulent flow lower Reynolds number limit — Reynolds number above which the flow is turbulent**

4e+3 (default) | positive unitless scalar

Reynolds number below which the pipe flow begins to transition from turbulent to laminar. This value is the minimum Reynolds number corresponding to fully developed turbulent flow.

**Shape factor for laminar flow viscous friction — Dimensionless factor used to capture the effect of geometry on viscous friction losses**

64 (default) | positive unitless scalar

Dimensionless factor used to capture the effects of cross-sectional geometry on the viscous friction losses incurred in the laminar flow regime. Typical values are 64 for a circular cross section, 57 for a square cross section, and 62 for a rectangular cross section with an aspect ratio of 2.

**Heat Transfer****External environment heat transfer coefficient — Heat transfer coefficient between the environment and the pipe wall**100 W/(m<sup>2</sup>\*K) (default) | positive scalar with units of power/(area\*temperature)

Heat transfer coefficient for heat exchange between the environment (at port **H**) and the outer surface of the pipe wall. If this parameter is set to *inf*, then the thermal resistance between the environment and the wall is assumed to be zero. The pipe wall then has a uniform temperature equal to that associated with port **H**.

**Wall thickness — Average thickness of the pipe wall material**

0 m (default) | positive scalar with units of length

Average thickness of the pipe wall material. If this value is set to 0, then both thermal resistance due to conduction through the pipe wall and thermal storage due to the thermal mass of the pipe wall are assumed to be negligible.

**Wall thermal conductivity — Thermal conductivity of the pipe wall material**

390 W/(m\*K) (default) | positive scalar with units of power/(length\*temperature)

Thermal conductivity of the pipe wall material. If this parameter is set to *inf*, then thermal resistance due to conduction through the pipe wall is assumed to be negligible.

**Wall specific heat — Heat capacity per unit mass of pipe wall material**

390 J/kg/K (default) | positive scalar with units of energy/(mass\*temperature)

Heat capacity per unit mass of the pipe wall material. If this parameter is set to 0, then thermal storage due to the thermal mass of the pipe is assumed to be negligible.

**Wall density — Mass density of the pipe wall material**9e3 kg/m<sup>3</sup> (default) | positive scalar with units of mass/volume

Mass density of the pipe wall material. If this parameter is set to 0, then thermal storage due to the thermal mass of the pipe wall is assumed to be negligible.

**Ratio of external fins surface area to no-fin surface area — Ratio of heat transfer surface area with external fins to that without**

0 (default) | positive unitless scalar

Ratio of the total heat transfer surface area of the fins on the external side of the pipe wall to that of the pipe wall without any fins. The presence of fins serves to enhance the convective heat transfer between the pipe wall and the environment.

**External fin efficiency – Ratio of actual to ideal heat exchange rates with external fins**

0.5 (default) | positive unitless scalar

Ratio of the actual heat exchange rate between the external fins and the environment to its ideal value (if the fins were entirely held at the temperature of the pipe wall). This parameter is a function of fin geometry.

**Ratio of internal fins surface area to no-fin surface area – Ratio of heat transfer surface area with internal fins to that without**

0 (default) | positive unitless scalar

Ratio of the total heat transfer surface area of the fins on the internal side of the pipe wall to that of the pipe wall without any fins. The presence of fins serves to enhance the convective heat transfer between the pipe wall and the fluid.

**Internal fin efficiency – Ratio of actual to ideal heat exchange rates with internal fins**

0.5 (default) | positive unitless scalar

Ratio of the actual heat exchange rate between the internal fins and the environment to its ideal value (if the fins were entirely held at the temperature of the pipe wall). This parameter is a function of fin geometry.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow inside tubes (default) | Colburn equation

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- **Colburn equation.** Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$ . In the liquid and vapor zones, the heat transfer coefficient is based on the Colburn equation. In the liquid-vapor mixture zone, the heat transfer coefficient is based on the Cavallini-Zecchin equation.
- **Correlation for flow inside tubes.** Use this setting to calculate the heat transfer coefficient for pipe flows. In the liquid and vapor zones, the heat transfer coefficient is calculated with the Gnielinski correlation. In the liquid-vapor mixture zone, the heat transfer coefficient is calculated with the Cavallini-Zecchin equation.

**Coefficients [a, b, c] for  $aRe^bPr^c$  in liquid zone – Colburn equation coefficients in liquid zone**

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which the block calculates by using the Colburn equation for each zone. The general form of the Colburn equation is:

$$Nu = aRe^bPr^c.$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Coefficients [a, b, c] for  $aRe^bPr^c$  in mixture zone – Cavallini-Zecchin equation coefficients in mixture zone**

[.05, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients for the Cavallini-Zecchin equation. Each fluid zone has a distinct Nusselt number, which the block calculates in the mixture zone by using the Cavallini-Zecchin equation:

$$Nu = \frac{aRe_{SL}^b Pr_{SL}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{Out} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{In} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) (x_{Out} - x_{In})}$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Coefficients [a, b, c] for  $aRe^bPr^c$  in vapor zone – Colburn equation coefficients in vapor zone**

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which the block calculates by using the Colburn equation for each zone. The general form of the Colburn equation is:

$$Nu = aRe^b Pr^c.$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Nusselt number for laminar flow heat transfer – Ratio of convective to conductive heat exchange rates in the laminar flow regime**

3.66 (default)

Ratio of convective to conductive heat exchange rates in the laminar flow regime. This parameter is a function of pipe cross section geometry. Typical values are 3.66 for a circular cross section, 2.98 for a square cross section, and 3.39 for a rectangular cross section with an aspect ratio of 2.

**Effects and Initial Conditions Tab****Initial fluid energy specification – Thermodynamic variable whose initial value to set**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Thermodynamic variable in terms of which to define the initial conditions of the component.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- **Temperature** — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- **Vapor quality** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Vapor void fraction** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

**Initial pressure — Absolute pressure at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the pipe at the start of simulation, specified against absolute zero.

**Initial temperature — Absolute temperature at the start of simulation**

293.15 K (default) | scalar or two-element vector with units of temperature

Fluid temperature in the pipe at the start of simulation. This parameter can be a scalar or a 2-element vector. If it is a scalar, the initial temperature is assumed to be uniform throughout the pipe. If it is a vector, the initial temperature is assumed to vary linearly between the ports. The first vector element gives the initial temperature at the inlet and the second vector element that at the outlet.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Temperature.

**Initial vapor quality — Mass fraction of vapor at the start of simulation**

0.5 (default) | unitless scalar between 0 and 1

Vapor quality, or mass fraction of vapor, in the pipe at the start of simulation. This parameter can be a scalar or a 2-element vector. If it is a scalar, the initial vapor quality is assumed to be uniform throughout the pipe. If it is a vector, the initial vapor quality is assumed to vary linearly between the ports. The first vector element gives the initial vapor quality at the inlet and the second vector element that at the outlet.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Vapor quality.

**Initial vapor void fraction — Volume fraction of vapor at the start of simulation**

0.5 (default) | unitless scalar between 0 and 1

Vapor void fraction, or vapor volume fraction, in the pipe at the start of simulation. This parameter can be a scalar or a 2-element vector. If it is a scalar, the initial vapor void fraction is assumed to be uniform throughout the pipe. If it is a vector, the initial vapor void fraction is assumed to vary linearly between the ports. The first vector element gives the initial vapor void fraction at the inlet and the second vector element that at the outlet.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Vapor void fraction.

**Initial specific enthalpy — Specific enthalpy at the start of simulation**

1500 kJ/kg (default) | scalar with units of energy/mass

Specific enthalpy of the fluid in the pipe at the start of simulation. This parameter can be a scalar or a 2-element vector. If it is a scalar, the initial specific enthalpy is assumed to be uniform throughout the pipe. If it is a vector, the initial specific enthalpy is assumed to vary linearly between the ports. The first vector element gives the initial specific enthalpy at the inlet and the second vector element that at the outlet.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Specific enthalpy.

**Initial specific internal energy — Specific internal energy at the start of simulation**

1500 kJ/kg (default) | scalar with units of energy/mass

Specific internal energy of the fluid in the pipe at the start of simulation. This parameter can be a scalar or a 2-element vector. If it is a scalar, the initial specific internal energy is assumed to be uniform throughout the pipe. If it is a vector, the initial specific internal energy is assumed to vary linearly between the ports. The first vector element gives the initial specific internal energy at the inlet and the second vector element that at the outlet.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Specific internal energy.

## Version History

Introduced in R2018b

**Parameterize using a new heat transfer coefficient model**

The 3-Zone Pipe (2P) block now allows you to more explicitly control the heat transfer process. You can set the new **Heat transfer coefficient model** parameter to:

- Correlation for flow inside tubes — The Gnielinski correlation predicts heat transfer of turbulent flows in subcooled liquid or superheated vapor zones, and the Cavallini-Zecchin correlation predicts the heat transfer of turbulent flows in the liquid-vapor mixture zone. The block predefines the coefficients  $a$ ,  $b$ , and  $c$ . This is how the block operates in previous releases.
- Colburn equation — The block allows you to define the coefficients  $a$ ,  $b$ , and  $c$  for each flow zone by using the **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in liquid zone**, **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in mixture zone**, and **Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in vapor zone** parameters. You specify these parameters as three-element vectors where the first element is  $a$ , the second is  $b$ , and the third is  $c$ .



## References

- [1] White, F.M., *Fluid Mechanics*, 7<sup>th</sup> Ed, Section 6.8. McGraw-Hill, 2011.
- [2] Çengel, Y.A., *Heat and Mass Transfer—A Practical Approach*, 3<sup>rd</sup> Ed, Section 8.5. McGraw-Hill, 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

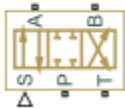
## See Also

Receiver Accumulator (2P)

## 4-Way Directional Valve

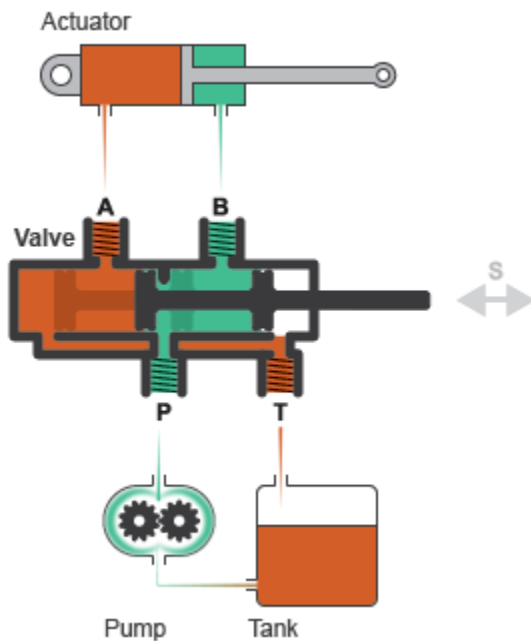
Four-port three-position directional control valve

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Directional Valves



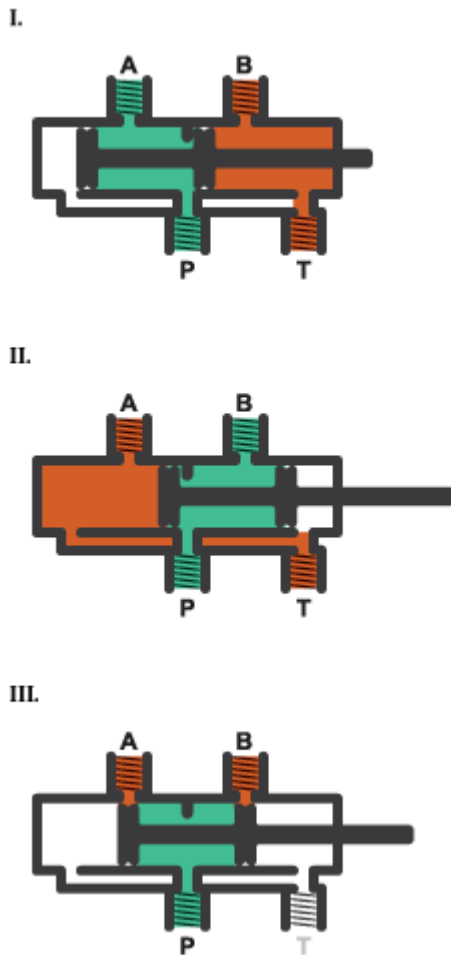
### Description

The 4-Way Directional Valve block represents a directional control valve with four ports and three positions, or flow paths. The ports connect to what in a typical model are a hydraulic pump (port **P**), a storage tank (port **T**), and a double-acting actuator (ports **A** and **B**). Fluid can flow from the pump to the actuator via path **P-A** or **P-B** and from the actuator to the tank via path **A-T** or **B-T**—depending on the working side of the actuator.



### Typical Valve Setup

In the default configuration, one valve position corresponds to the **P-A** and **B-T** flow paths maximally open and the **P-B** and **A-T** flow paths maximally closed (position **I** in the figure). Another valve position corresponds to the inverse configuration, with **P-B** and **A-T** maximally open and **P-A** and **B-T** maximally closed (position **II**). The third valve position corresponds to all flow paths maximally closed (position **III**). A translating spool serves as the valve control member and determines the position that the valve is in—**I**, **II**, **III**, or in between.



### Valve Positions

Physical signal port **S** controls the spool displacement. In the default configuration, a zero displacement signal corresponds to valve position **III**. A positive displacement signal shifts the spool toward valve position **I**. A negative displacement shifts the spool toward valve position **II**. The spool displacement acts indirectly by setting the spool position relative to each flow path—a length known here as the *orifice opening*. The orifice opening in turn determines the opening area of the respective flow path.

### Orifice Openings

The orifice opening of a flow path depends partly on its *opening offset*—the orifice opening of a flow path at zero spool displacement. The block models only the effects of the opening offsets. An offset can be due to a change in distance between ports or spool lands—the thick disks built into the spool to obstruct flow. It can also be due to a change in the thicknesses of the spool lands. The orifice openings are computed separately for each flow path in terms of the respective opening offset:

$$h_{PA} = h_{PA0} + x$$

$$h_{PB} = h_{PB0} - x$$

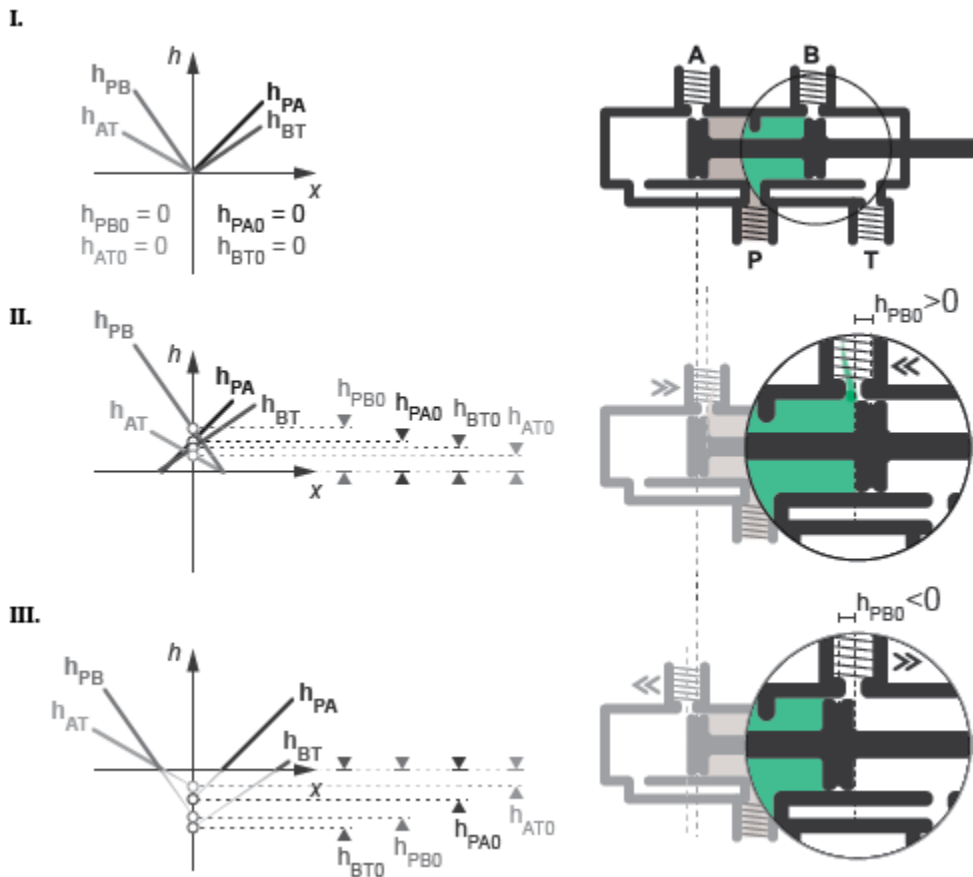
$$h_{AT} = h_{AT0} - x$$

$$h_{BT} = h_{BT0} + x$$

where:

- $h_{PA}$ ,  $h_{PB}$ ,  $h_{AT}$ , and  $h_{BT}$  are the orifice openings of the **P-A**, **P-B**, **A-T**, and **P-B** flow paths. The orifice openings are computed during simulation.
- $h_{PA0}$ ,  $h_{PB0}$ ,  $h_{AT0}$ , and  $h_{BT0}$  are the orifice opening offsets of the **P-A**, **P-B**, **A-T**, and **P-B** flow paths. The opening offsets are specified in the **Valve opening offsets** tab.
- $x$  is the spool displacement relative to what in the zero-offset case is a fully closed valve. The spool displacement is specified through physical signal port **S**.

The figure shows the effects of the opening offsets on the orifice openings. Plot **I** corresponds to the default configuration with both opening offsets equal to zero. Plot **II** corresponds to a valve with both opening offsets greater than zero and plot **III** to a valve with both opening offsets smaller than zero. These cases are similar in behavior to zero-lapped (**I**), underlapped (**II**) and overlapped (**III**) valves. The valve schematics to the right show what the offset might look like. The circle highlights the offset in path **P-B**.



**Zero (I), Positive (II), and Negative (III) Opening Offsets**

An underlapped valve is always partially open and allows some flow at all spool displacements. An overlapped valve is fully closed over an extended range of spool displacements and requires longer

spool travel to open. The table summarizes the opening offsets for zero-lapped, underlapped, and overlapped valves. Other configurations are possible—e.g., with one opening offset positive and the other negative.

Valve Lapping	Opening Offsets
Zero-lapped (default)	All zero
Underlapped	All positive
Overlapped	All negative

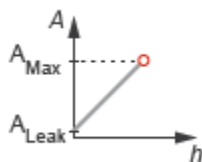
### Opening Areas

The **Model parameterization** setting determines the calculations used for the opening areas of the flow paths—or, in the **Pressure-flow characteristic** case, the volumetric flow rates. The calculations are based on orifice parameters or tabulated data sets specified in the **Model Parameterization** tab. The block uses the same data for all flow paths if the **Area characteristics** parameter in the **Basic Parameters** tab is set to **Identical** for all flow paths and different data otherwise. Model parameterizations that you can select include:

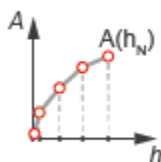
- **Maximum area and opening** — Specify the maximum opening area and the corresponding orifice opening. The opening area is a linear function of the orifice opening,

$$A_{AT} = \frac{A_{AT, Max}}{h_{AT, Max}} h_{AT} + A_{Leak},$$

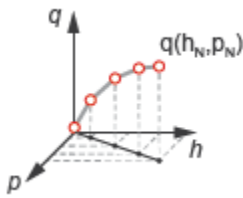
where  $A$  is the opening area and  $h$  the orifice opening of a given flow path. The subscript **Max** refers to a fully open orifice and the subscript **Leak** to a fully closed orifice—one with internal leakage flow area only. The figure shows a plot of the linear function  $A(h)$ .



- **Area vs. opening table** — Specify the opening area at discrete orifice openings as a 1-D lookup table. The opening area is computed for a given orifice opening by interpolation or extrapolation of the tabulated data. The figure shows a conceptual plot of the tabulated function  $A(h)$ .



- **Pressure-flow characteristic** — Specify the volumetric flow rate at discrete orifice openings and pressure differentials as a 2-D lookup table. The opening area is computed for a given orifice opening and pressure differential by interpolation or extrapolation of the tabulated data. The figure shows a conceptual plot of the tabulated function  $q(h, p)$ .



### Flow Regime and Internal Leakage

Volumetric flow rates are computed analytically in the Maximum area and opening and Area vs. opening table parameterizations. The calculations are based on additional block parameters such as the flow discharge coefficient and account for the effects of flow regime—laminar or turbulent. Regime transition occurs at the specified critical laminar flow ratio or critical Reynolds number.

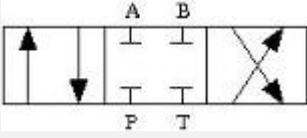
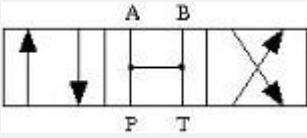
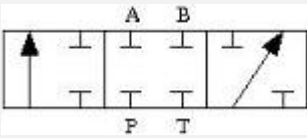
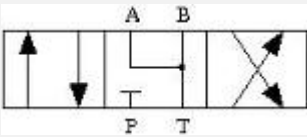
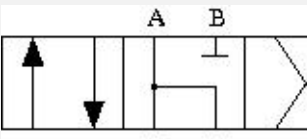
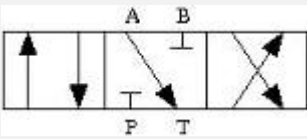
The Maximum area and opening and Area vs. opening table parameterizations also account for a small internal leakage area even in the fully closed state. The leakage area ensures that portions of the hydraulic network do not become isolated when a flow path is closed. Isolated, or “hanging”, network portions affect the computational efficiency of the model and can cause simulation to fail.

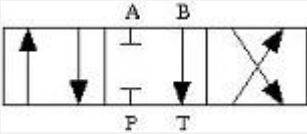
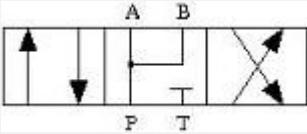
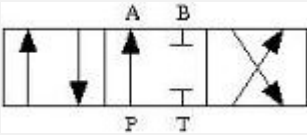
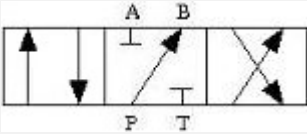
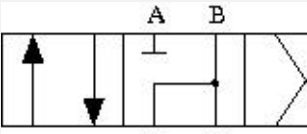
The effects of flow regime and internal leakage are assumed to be reflected in the tabulated flow rate data specified directly in the Pressure-flow characteristic parameterization.

### Valve Configurations

The opening offsets are by default zero. This configuration corresponds to a valve with all flow paths closed in the neutral position (**III** in the “Valve Positions” on page 1-117 schematic). Many other configurations exist. You can model a specific configuration by setting the opening offsets as shown in the table. All opening offset parameters are in the **Valve opening offsets** tab of the block property inspector

## The 4-Way Directional Valve Configurations

No	Configuration	Initial Openings
1		<p>All four orifices are overlapped in neutral position:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>
2		<p>All four orifices are open (underlapped) in neutral position:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &gt; 0</li> <li>• <b>Orifice P-B initial opening</b> &gt; 0</li> <li>• <b>Orifice A-T initial opening</b> &gt; 0</li> <li>• <b>Orifice B-T initial opening</b> &gt; 0</li> </ul>
3		<p>Orifices P-A and P-B are overlapped. Orifices A-T and B-T are overlapped for more than valve stroke:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; - <i>valve_stroke</i></li> <li>• <b>Orifice B-T initial opening</b> &lt; - <i>valve_stroke</i></li> </ul>
4		<p>Orifices P-A and P-B are overlapped, while orifices A-T and B-T are open:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &gt; 0</li> <li>• <b>Orifice B-T initial opening</b> &gt; 0</li> </ul>
5		<p>Orifices P-A and A-T are open in neutral position, while orifices P-B and B-T are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &gt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &gt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>
6		<p>Orifice A-T is initially open, while all three remaining orifices are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &gt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>

No	Configuration	Initial Openings
7		<p>Orifice B-T is initially open, while all three remaining orifices are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &gt; 0</li> </ul>
8		<p>Orifices P-A and P-B are open, while orifices A-T and B-T are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &gt; 0</li> <li>• <b>Orifice P-B initial opening</b> &gt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>
9		<p>Orifice P-A is initially open, while all three remaining orifices are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &gt; 0</li> <li>• <b>Orifice P-B initial opening</b> &lt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>
10		<p>Orifice P-B is initially open, while all three remaining orifices are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &gt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &lt; 0</li> </ul>
11		<p>Orifices P-B and B-T are open, while orifices P-A and A-T are overlapped:</p> <ul style="list-style-type: none"> <li>• <b>Orifice P-A initial opening</b> &lt; 0</li> <li>• <b>Orifice P-B initial opening</b> &gt; 0</li> <li>• <b>Orifice A-T initial opening</b> &lt; 0</li> <li>• <b>Orifice B-T initial opening</b> &gt; 0</li> </ul>

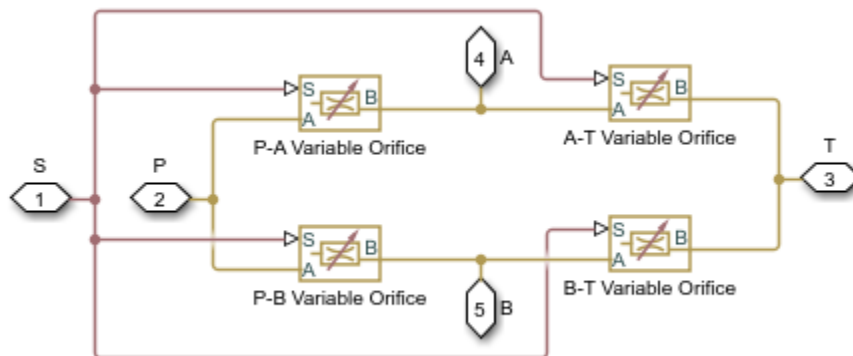
### Structural Component Diagram

The block is a composite component with four Variable Orifice blocks driven by a single physical signal. Blocks Variable Orifice P-A and Variable Orifice P-B represent the **P-A** and **P-B** flow paths. Blocks Variable orifice A-T and Variable orifice B-T represent the **A-T** and **B-T** flow paths. The physical signal is specified through Connection Port block **S**.

The **Orifice orientation** block parameters are set so that a positive signal acts to open Variable Orifice P-A and Variable Orifice B-T while closing Variable Orifice A-T and Variable Orifice P-B. A negative signal has the opposite effect—acting to open Variable Orifice A-T



and Variable Orifice P-B while closing Variable Orifice P-A and Variable Orifice B-T.



## Valve Structural Diagram

### Assumptions

- Fluid inertia is ignored.
- Control member loading due to inertial, spring, and other forces is ignored.
- All valve orifices are assumed identical in size unless otherwise specified.

## Ports

### Input

**S – Control member displacement, m**  
physical signal

Physical signal input port for the control member displacement.

### Conserving

**P – Pressure supply connection port**  
hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the pressure supply line inlet.

**T – Return line connection port**  
hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the return line connection.

**A – Actuator connection port**  
hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the actuator connection port.

**B – Actuator connection port**  
hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the actuator connection port.

## Parameters

### Basic Parameters

#### Area characteristics — Symmetry of the flow path opening characteristics

Identical for all flow paths (default) | Different for each flow path

Choice of different or identical flow path opening characteristics. Select **Different for each flow path** to specify flow path parameters or tabulated data separately for each flow path.

#### Model parameterization — Types of valve parameters to use as input

Maximum area and opening (default) | Area vs. opening table | Pressure-flow characteristic

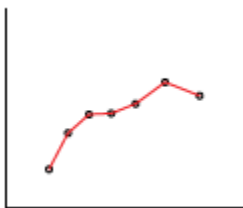
Parameterization of the valve model. Options include:

- **By maximum area and opening** — Specify the maximum orifice opening and opening area. The opening area varies linearly with the spool displacement specified at physical signal port **S**.
- **By area vs. opening table** — Specify the flow path opening area at discrete orifice openings as a 1-D lookup table. The opening area is computed by interpolation or extrapolation of the tabulated data.
- **By pressure-flow characteristic** — Specify the flow path volumetric flow rates at discrete orifice openings and pressure differentials. The flow rate is computed by interpolation or extrapolation of the tabulated data.

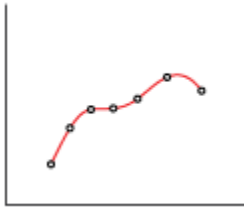
#### Interpolation method — Method of computing values inside the lookup table range

Linear (default) | Smooth

Method of computing values inside the tabulated data range. The **Linear** method joins adjacent data points with straight line or surface segments with generally discontinuous slope at the segment boundaries. Surface segments are used in the 2-D lookup table specified in the **Pressure-flow characteristic** model parameterization.



The **Smooth** method replaces the straight segments with curved versions that have continuous slope everywhere inside the tabulated data range. The segments form a smooth line or surface passing through all of the tabulated data points without the discontinuities in first-order derivatives characteristic of the **Linear** interpolation method.



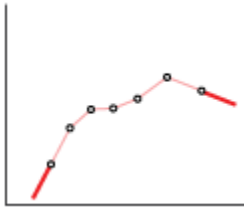
### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to By area vs. opening table or Pressure-flow characteristic.

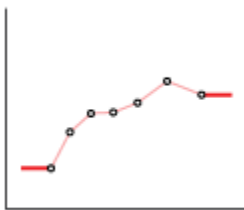
### Extrapolation method – Method of computing values outside of the lookup table range

Linear (default) | Nearest

Method of computing values outside of the tabulated data range. The Linear method extends the line segment drawn between the last two data points at each end of the data range outward with a constant slope.



The Nearest method extends the last data point at each end of the data range outward as a horizontal line with constant value.



### Dependencies

This parameter is active when the **Model Parameterization** parameter is set to By area vs. opening table or Pressure-flow characteristic.

### Flow discharge coefficient – Semi-empirical parameter for valve capacity characterization

0.7 (default) | unitless scalar between 0 and 1

Ratio of the actual and theoretical flow rates through the valve. This parameter depends on the geometrical properties of the valve. Values are usually provided in textbooks and manufacturer data sheets.

**Dependencies**

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening table`.

**Leakage area — Internal leakage area between valve inlets**

1e-12 m<sup>2</sup> (default) | positive scalar in units of area

Total area of internal leaks in the completely closed state. The purpose of this parameter is to maintain the numerical integrity of the fluid network by preventing a portion of that network from becoming isolated when the valve is completely closed.

**Dependencies**

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening table`.

**Laminar transition specification — Choice of parameter used to define the laminar-turbulent transition**

Pressure ratio (default) | Reynolds number

Select the parameter to base the laminar-turbulent transition on. Options include:

- `Pressure ratio` — Flow transitions between laminar and turbulent at the pressure ratio specified in the **Laminar flow pressure ratio** parameter. Use this option for the smoothest and most numerically robust flow transitions.
- `Reynolds number` — The transition occurs at the Reynolds number specified in the **Critical Reynolds number** parameter. Flow transitions are more abrupt and can cause simulation issues at near-zero flow rates.

**Dependencies**

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening table`.

**Laminar flow pressure ratio — Pressure ratio at the laminar-turbulent flow transition**

0.999 (default) | unitless scalar between 0 and 1

Pressure ratio at which the flow transitions between the laminar and turbulent regimes. The pressure ratio is the fraction of the outlet pressure over the inlet pressure.

**Dependencies**

This parameter is active when the **Model Parameterization** parameter is set to `By maximum area and opening` or `By area vs. opening table` and the **Laminar transition specification** parameter is set to `Pressure ratio`.

**Critical Reynolds number — Reynolds number at the laminar-turbulent flow transition**

12 (default) | unitless positive scalar

Maximum Reynolds number for laminar flow. This parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value, 12, corresponds to a round orifice in thin material with sharp edges.

**Dependencies**

This parameter is active when the **Model Parameterization** parameter is set to By maximum area and opening or By area vs. opening table and the **Laminar transition specification** parameter is set to Reynolds number.

**Model Parameterization: Maximum area and opening****Maximum opening — Orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Orifice opening at which the opening area of a flow path is a maximum. The maximum opening is the same for all flow paths when this parameter is exposed. For the orifice opening definitions, see “Orifice Openings” on page 1-117.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Maximum area and opening.

**Maximum opening area — Maximum cross-sectional area of a flow path**

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of a flow path. The maximum opening areas are the same for all paths when this parameter is exposed. For the opening area calculations, see “Opening Areas” on page 1-119.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Maximum area and opening.

**P-A, maximum opening — P-A orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Control member position at which the P-A opening area is equal to the **P-A, maximum opening area** parameter value.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**P-A, maximum opening area — Maximum flow area of the P-A flow path**

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **P-A** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Areas” on page 1-119.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**P-B, maximum opening — P-B Orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Control member position at which the P-B opening area is equal to the **P-B, maximum opening area** parameter value.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**P-B, maximum opening area — Maximum flow area of the P-B flow path**

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **P-B** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Areas” on page 1-119.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**A-T, maximum opening — A-T Orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Control member position at which the A-T opening area is equal to the **A-T, maximum opening area** parameter value.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**A-T, maximum opening area — Maximum flow area of the A-T flow path**

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **A-T** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Areas” on page 1-119.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**B-T, maximum opening — B-T Orifice opening at which the opening area is a maximum**

0.005 m (default) | positive scalar with units of length

Control member position at which the B-T opening area is equal to the **B-T, maximum opening area** parameter value.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Maximum area and opening.

**B-T, maximum opening area — Maximum flow area of the B-T flow path**

0.5e-4 m<sup>2</sup> (default) | positive scalar with units of area

Maximum cross-sectional area of the **B-T** flow path. The maximum opening areas are different for each flow path when this parameter is exposed. For the opening area calculations, see “Opening Areas” on page 1-119.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Maximum area and opening**.

#### Model Parameterization: Area vs. opening table

**Opening vector — Orifice openings at which to specify the flow path opening areas**  
 [-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of orifice openings used to construct the opening area 1-D lookup table for all flow paths. The opening characteristics are identical for all flow paths when this parameter is exposed. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Identical** for all flow paths and the **Model parameterization** parameter is set to **Area vs. opening table**.

**Opening area vector — Opening areas corresponding to the orifice openings specified in the Opening vector parameter**  
 [1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of flow path opening areas corresponding to the specified orifice openings. The opening characteristics are identical for all flow paths when this parameter is exposed. The number of elements in the array must match the number of elements in the **Opening vector** parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Identical** for all flow paths and the **Model parameterization** parameter is set to **Area vs. opening table**.

**P-A, opening vector — P-A orifice openings at which to specify the P-A opening area**  
 [-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **P-A** orifice openings used to construct the opening area 1-D lookup table for the **P-A** flow path. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

**P-A, opening area vector — P-A opening areas corresponding to the orifice openings specified in the P-A, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **P-A** opening areas corresponding to the specified **P-A** orifice openings. The number of elements in the array must match the number of elements in the **P-A, opening vector** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

**P-B, opening vector — P-B orifice openings at which to specify the P-B opening area**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **P-B** orifice openings used to construct the opening area 1-D lookup table for the **P-B** flow path. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

**P-B, opening area vector — P-B opening areas corresponding to the orifice openings specified in the P-B, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **P-B** opening areas corresponding to the specified **P-B** orifice openings. The number of elements in the array must match the number of elements in the **P-B, opening vector** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.

**A-T, opening vector — A-T orifice openings at which to specify the A-T opening area**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **A-T** orifice openings used to construct the opening area 1-D lookup table for the **A-T** flow path. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Area vs. opening table**.



**A-T, opening area vector — A-T opening areas corresponding to the orifice openings specified in the A-T, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **A-T** opening areas corresponding to the specified **A-T** orifice openings. The number of elements in the array must match the number of elements in the **A-T, opening vector** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Area vs. opening table.

**B-T, opening vector — B-T orifice openings at which to specify the B-T opening area**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of **B-T** orifice openings used to construct the opening area 1-D lookup table for the **B-T** flow path. The number of elements in the array determines the number of elements in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Area vs. opening table.

**B-T, opening area vector — B-T opening areas corresponding to the orifice openings specified in the B-T, opening vector parameter**

[1.0e-9, 2.0352e-7, 4.0736e-5, 0.00011438, 0.00034356] m<sup>2</sup> (default) | numerical array with units of area

Array of **B-T** opening areas corresponding to the specified **B-T** orifice openings. The number of elements in the array must match the number of elements in the **B-T, opening vector** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Area vs. opening table.

**Model Parameterization: Pressure-flow characteristic****Opening vector, s — Orifice openings at which to specify the flow rate tabulated data**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of orifice openings used to construct the volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of rows in the table. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

**Pressure differential vector, dp – Pressure differentials at which to specify the flow rate data**

[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0] Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of columns in the table. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

**Volumetric flow rate table, q(s,dp) – Volumetric flow rates at the specified control member displacements and pressure differentials**

5-by-6 matrix with elements between -0.0344 and 0.0344 m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates corresponding to the specified orifice openings and pressure differentials. The number of rows must match the number of elements in the **Opening vector, s** parameter. The number of columns must match the number of elements in the **Pressure differential vector, dp** parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Identical for all flow paths and the **Model parameterization** parameter is set to Pressure-flow characteristic.

**P-A, opening vector, s – Orifice openings at which to specify the P-A flow rate data**

[-0.002, 0.0, 0.002, 0.005, 0.015] m (default) | numerical array with units of length

Array of P-A orifice openings used to construct the P-A volumetric flow rate 2-D lookup table. The number of elements in the array determines the number of rows in the table. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Pressure-flow characteristic.

**P-A, pressure differential vector, dp – Pressure differentials at which to specify the flow rate data for the P-A flow path**

[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0] Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the P-A flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### **P-A, volumetric flow rate table, $q(s, dp)$ – Volumetric flow rates at the specified control member displacements and pressure differentials for the P-A flow path**

5-by-6 matrix with elements between  $-0.0344$  and  $0.0344$  m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates through the P-A flow path at the specified control member displacements and pressure differentials. The number of rows must match the number of elements in the **P-A, opening vector,  $s$**  parameter. The number of columns must match the number of elements in the **P-A, pressure differential vector,  $dp$**  parameter.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### **P-B, opening vector, $s$ – Control member displacements at which to specify the flow rate data for the P-B flow path**

$[-0.002, 0.0, 0.002, 0.005, 0.015]$  m (default) | numerical array with units of length

Array of control member displacements used to construct the volumetric flow rate 2-D lookup table for the P-B flow path. The number of elements in the array determines the number of rows in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

#### Dependencies

This parameter is active when the **Area characteristics** parameter is set to Different for each flow path and the **Model parameterization** parameter is set to Pressure-flow characteristic.

#### **P-B, pressure differential vector, $dp$ – Pressure differentials at which to specify the flow rate data for the P-B flow path**

$[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0]$  Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the P-B flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for Linear interpolation and three elements for Smooth interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to `Different` for each flow path and the **Model parameterization** parameter is set to `Pressure-flow` characteristic.

**P-B, volumetric flow rate table,  $q(s,dp)$  — Volumetric flow rates at the specified control member displacements and pressure differentials for the P-B flow path**

5-by-6 matrix with elements between  $-0.0344$  and  $0.0344$  m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates through the P-B flow path at the specified control member displacements and pressure differentials. The number of rows must match the number of elements in the **P-B, opening vector,  $s$**  parameter. The number of columns must match the number of elements in the **P-A, pressure differential vector,  $dp$**  parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to `Different` for each flow path and the **Model parameterization** parameter is set to `Pressure-flow` characteristic.

**A-T, opening vector,  $s$  — Control member displacements at which to specify the flow rate data for the A-T flow path**

`[-0.002, 0.0, 0.002, 0.005, 0.015]` m (default) | numerical array with units of length

Array of control member displacements used to construct the volumetric flow rate 2-D lookup table for the A-T flow path. The number of elements in the array determines the number of rows in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for `Linear` interpolation and three elements for `Smooth` interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to `Different` for each flow path and the **Model parameterization** parameter is set to `Pressure-flow` characteristic.

**A-T, pressure differential vector,  $dp$  — Pressure differentials at which to specify the flow rate data for the A-T flow path**

`[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0]` Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the A-T flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for `Linear` interpolation and three elements for `Smooth` interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**A-T, volumetric flow rate table,  $q(s, dp)$  — Volumetric flow rates at the specified control member displacements and pressure differentials for the A-T flow path**

5-by-6 matrix with elements between  $-0.0344$  and  $0.0344$  m<sup>3</sup>/s (default) | numerical array with units of length

Matrix with the volumetric flow rates through the A-T flow path at the specified control member displacements and pressure differentials. The number of rows must match the number of elements in the **A-T, opening vector,  $s$**  parameter. The number of columns must match the number of elements in the **A-T, pressure differential vector,  $dp$**  parameter.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**B-T, opening vector,  $s$  — Control member displacements at which to specify the flow rate data for the B-T flow path**

$[-0.002, 0.0, 0.002, 0.005, 0.015]$  m (default) | numerical array with units of length

Array of control member displacements used to construct the volumetric flow rate 2-D lookup table for the B-T flow path. The number of elements in the array determines the number of rows in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

**Dependencies**

This parameter is active when the **Area characteristics** parameter is set to **Different** for each flow path and the **Model parameterization** parameter is set to **Pressure-flow** characteristic.

**B-T, pressure differential vector,  $dp$  — Pressure differentials at which to specify the flow rate data for the B-T flow path**

$[-10000000.0, -5000000.0, -2000000.0, 2000000.0, 5000000.0, 10000000.0]$  Pa (default) | numerical array with units of pressure

Array of pressure differentials used to construct the volumetric flow rate 2-D lookup table for the B-T flow path. The number of elements in the array determines the number of columns in the table.

The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for **Linear** interpolation and three elements for **Smooth** interpolation.

### Dependencies

This parameter is active when the **Area characteristics** parameter is set to `Different` for each flow path and the **Model parameterization** parameter is set to `Pressure-flow` characteristic.

### **B-T, volumetric flow rate table, $q(s,dp)$ — Volumetric flow rates at the specified control member displacements and pressure differentials for the B-T flow path**

5-by-6 matrix with elements between  $-0.0344$  and  $0.0344$   $m^3/s$  (default) | numerical array with units of length

Matrix with the volumetric flow rates through the B-T flow path at the specified control member displacements and pressure differentials. The number of rows must match the number of elements in the **B-T, opening vector,  $s$**  parameter. The number of columns must match the number of elements in the **B-T, pressure differential vector,  $dp$**  parameter.

### Dependencies

This parameter is active when the **Area characteristics** parameter is set to `Different` for each flow path and the **Model parameterization** parameter is set to `Pressure-flow` characteristic.

### Valve Opening Offsets

#### **Between P-A — P-A orifice opening at zero spool displacement**

$0$  m (default) | scalar number with units of lengths

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $0$  corresponds to a zero-lapped valve.

#### **Between P-B — P-B orifice opening at zero spool displacement**

$0$  m (default) | scalar number with units of lengths

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $0$  corresponds to a zero-lapped valve.

#### **Between A-T — A-T orifice opening at zero spool displacement**

$0$  m (default) | scalar number with units of length

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $0$  corresponds to a zero-lapped valve.

#### **Between B-T — BT orifice opening at zero spool displacement**

$0$  m (default) | scalar number with units of length

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $0$  corresponds to a zero-lapped valve.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

2-Way Directional Valve | 3-Way Directional Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve A

Configuration A of hydraulic continuous 4-way directional valve

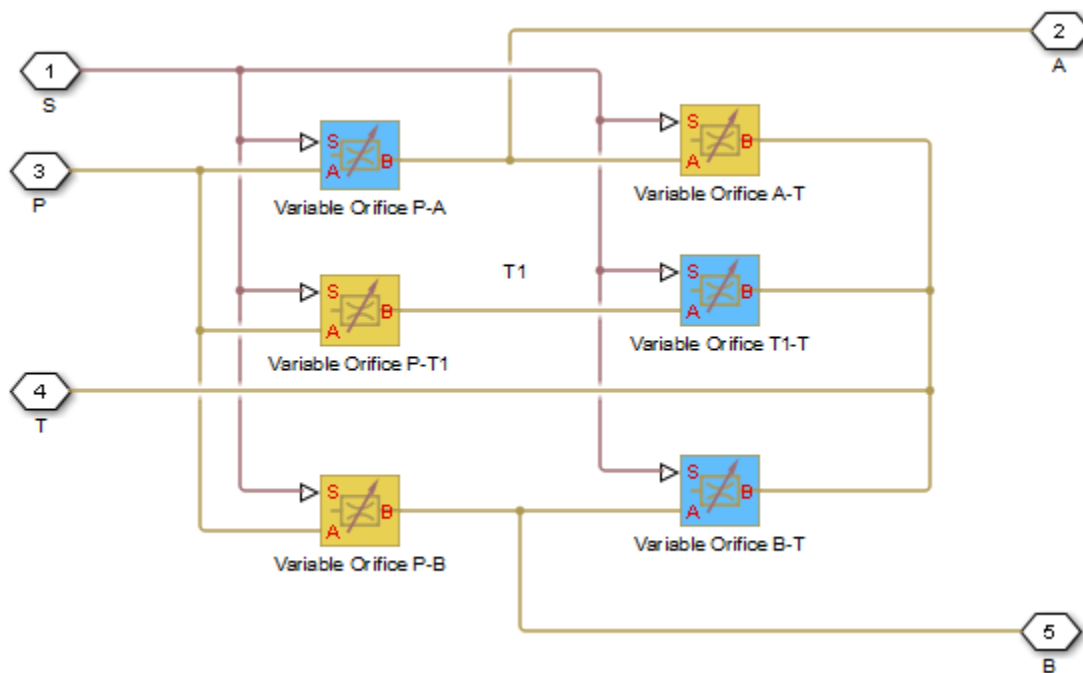


### Library

Directional Valves

### Description

The 4-Way Directional Valve A block simulates a configuration of hydraulic continuous 4-way directional valve where the valve unloads the pump in neutral position. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at



port S opens the orifices colored blue in the block diagram (orifices P-A, B-T, and T1-T ) and closes the orifices colored yellow (orifices A-T, P-B, and P-T1). As a result, the openings of the orifices are computed as follows:

$$h_{PA} = h_{PA0} + x$$

$$h_{PB} = h_{PB0} - x$$

$$h_{AT} = h_{AT0} - x$$

$$h_{BT} = h_{BT0} + x$$

$$h_{PT1} = h_{PT10} - x$$

$$h_{T1T} = h_{T1T0} + x$$

where

$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block
$h_{AT}$	Orifice opening for the Variable Orifice A-T block
$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{PT1}$	Orifice opening for the Variable Orifice P-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{AT0}$	Initial opening for the Variable Orifice A-T block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$h_{PT10}$	Initial opening for the Variable Orifice P-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-139
- “Valve Opening Offsets Tab” on page 1-142

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- By maximum area and opening — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member

displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.

- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve opening vector, *s*

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

### Valve passage area vector

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

### Pressure differential vector, *dp*

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

### Volumetric flow rate table, *q(s,dp)*

Specify the flow rates as an *m*-by-*n* matrix, where *m* is the number of valve openings and *n* is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
```

```
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Valve Opening Offsets Tab****Between ports P and A**

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and B**

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports A and T**

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports B and T**

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and T1**

Orifice opening of the **P-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## **Version History**

**Introduced in R2009b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

4-Way Directional Valve | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve B

Configuration B of hydraulic continuous 4-way directional valve

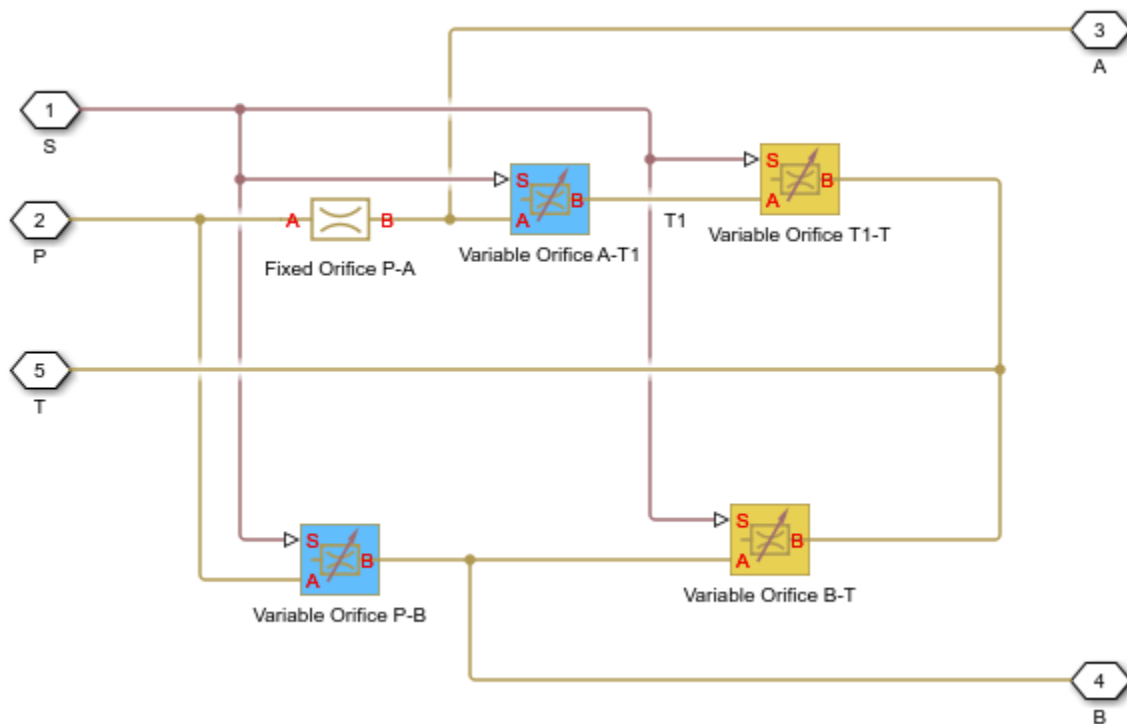


### Library

Directional Valves

### Description

The 4-Way Directional Valve B block simulates a configuration of hydraulic continuous 4-way directional valve where port A is permanently connected to port P, and all four ports are interconnected in neutral position. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of a Fixed Orifice block in the P-A path and four Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices A-T1 and P-B ) and closes the orifices colored yellow (orifices T1-T and B-T). As a result, the openings of the orifices are computed as follows:

$$h_{AT1} = h_{AT10} - x$$

$$h_{PB} = h_{PB0} - x$$

$$h_{T1T} = h_{T1T0} + x$$

$$h_{BT} = h_{BT0} + x$$

where

$h_{AT1}$	Orifice opening for the Variable Orifice A-T1 block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{AT10}$	Initial opening for the Variable Orifice A-T1 block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-145
- “Valve Opening Offsets Tab” on page 1-148

### Basic Parameters Tab

Compared to the Basic Parameters tab of the 4-Way Directional Valve block, there is one additional parameter:

#### Path P-A passage area

Specify the area of the P-A passage. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

The rest of the parameters on this tab are identical to those of the 4-Way Directional Valve block:

### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

#### **Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

#### **Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

#### **Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### **Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:



```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with

sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### **Valve Opening Offsets Tab**

#### **Between ports P and B**

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports B and T**

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports A and T1**

Orifice opening of the **A-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

## **Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## **Version History**

**Introduced in R2009b**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

### Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve C

Configuration C of hydraulic continuous 4-way directional valve

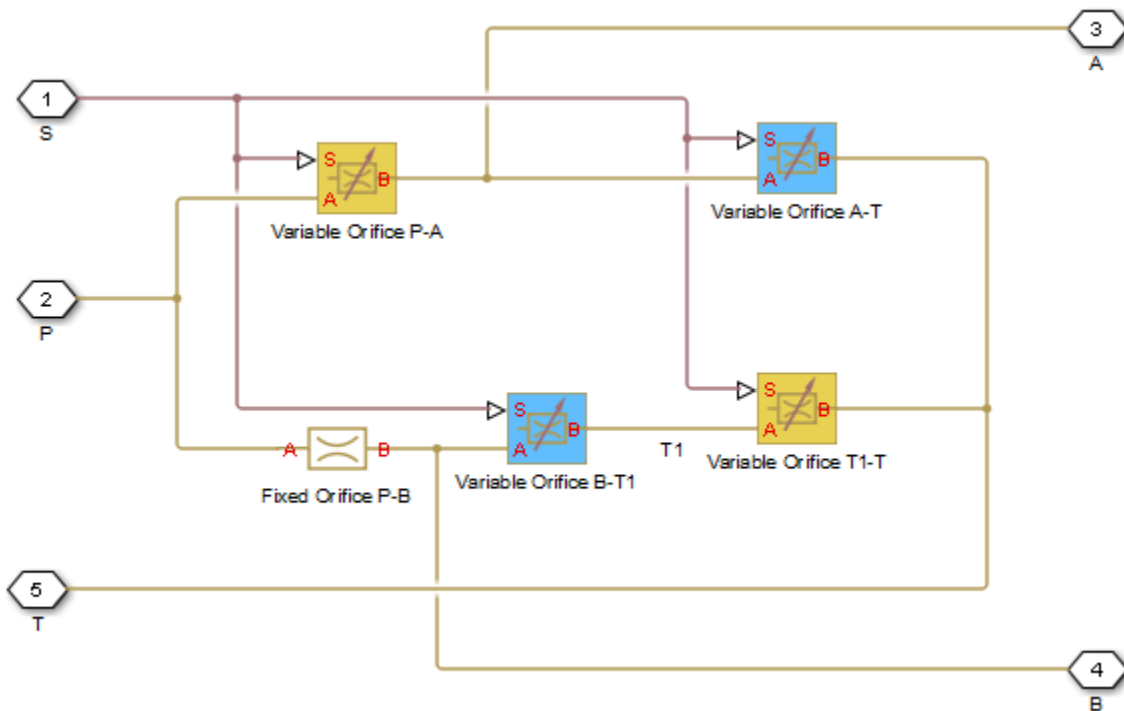


### Library

Directional Valves

### Description

The 4-Way Directional Valve C block simulates a configuration of hydraulic continuous 4-way directional valve where port P is connected to port A and port B is connected to port T in the left position; in the right position, both port A and port B are connected to P; and all ports are interconnected in neutral position. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of a Fixed Orifice block in the P-B path and four Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices B-T1 and A-T ) and closes the orifices colored yellow (orifices P-A and T1-T). As a result, the openings of the orifices are computed as follows:

$$h_{PA} = h_{PA0} - x$$

$$h_{AT} = h_{AT0} + x$$

$$h_{BT1} = h_{BT10} + x$$

$$h_{T1T} = h_{T1T0} - x$$

where

$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{AT}$	Orifice opening for the Variable Orifice A-T block
$h_{BT1}$	Orifice opening for the Variable Orifice B-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{BT10}$	Initial opening for the Variable Orifice B-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-151
- “Valve Opening Offsets Tab” on page 1-154

### Basic Parameters Tab

Compared to the Basic Parameters tab of the 4-Way Directional Valve block, there is one additional parameter:

#### Path P-B passage area

Specify the area of the P-B passage. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

The rest of the parameters on this tab are identical to those of the 4-Way Directional Valve block:

### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

#### **Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

#### **Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

#### **Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### **Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with

sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### **Valve Opening Offsets Tab**

#### **Between ports P and A**

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports A and T**

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports B and T1**

Orifice opening of the **B-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

## **Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## **Version History**

**Introduced in R2009b**



## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

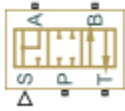
4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

### Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve D

Configuration D of hydraulic continuous 4-way directional valve

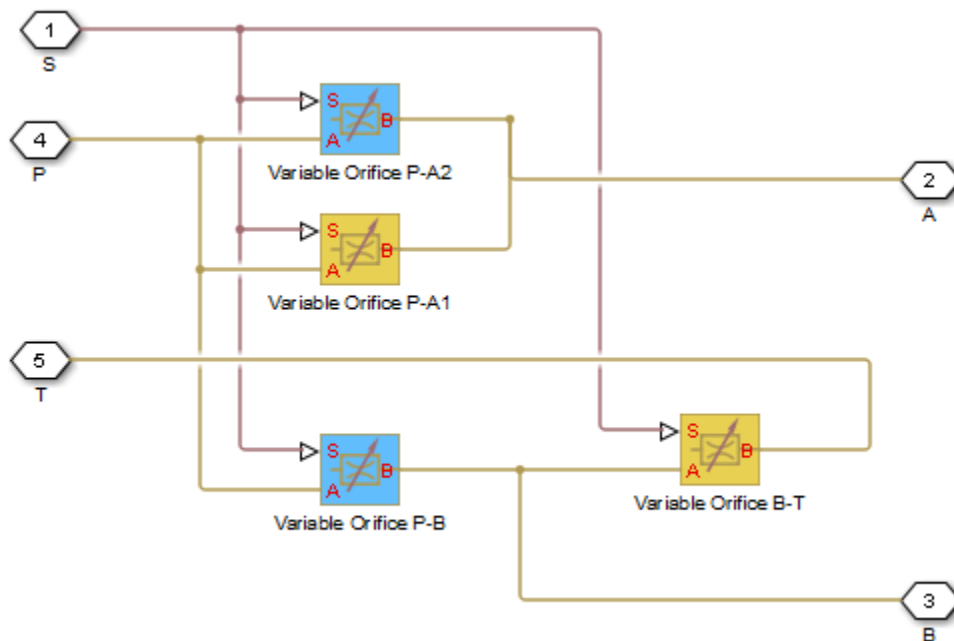


### Library

Directional Valves

### Description

The 4-Way Directional Valve D block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the left valve position. In the right position, port P is connected to port A, while port B is connected to port T. All connections are blocked in neutral position. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of four Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that

positive signal at port S opens the orifices colored blue in the block diagram (orifices P-A2 and P-B ) and closes the orifices colored yellow (orifices P-A1 and B-T). As a result, the openings of the orifices are computed as follows:

$$h_{PA1} = h_{PA10} - x$$

$$h_{PA2} = h_{PA20} + x$$

$$h_{PB} = h_{PB0} + x$$

$$h_{BT} = h_{BT0} - x$$

where

$h_{PA1}$	Orifice opening for the Variable Orifice P-A1 block
$h_{PA2}$	Orifice opening for the Variable Orifice P-A2 block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block
$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{PA10}$	Initial opening for the Variable Orifice P-A1 block
$h_{PA20}$	Initial opening for the Variable Orifice P-A2 block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-157
- “Valve Opening Offsets Tab” on page 1-160

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

**Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to By maximum area and opening.

**Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to By maximum area and opening.

**Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to By area vs. opening table, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to By pressure-flow characteristic, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

**Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to By area vs. opening table.

**Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

**Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

**Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## Valve Opening Offsets Tab

### Between ports P and A1

Orifice opening of the **P-A1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports P and A2

Orifice opening of the **P-A2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports P and B

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports B and T

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

## Ports

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## Version History

Introduced in R2009b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## **See Also**

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve E

Configuration E of hydraulic continuous 4-way directional valve

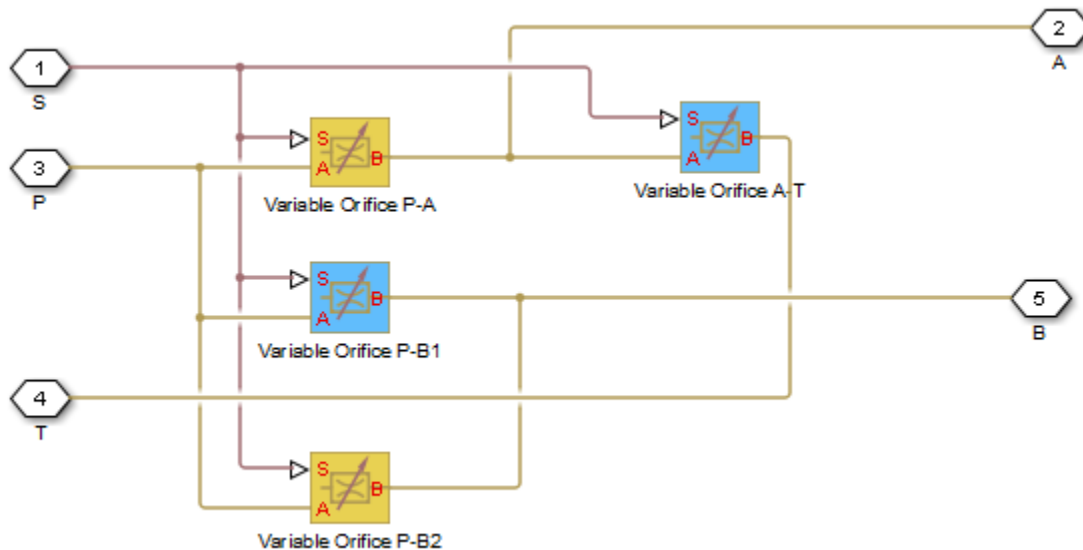


### Library

Directional Valves

### Description

The 4-Way Directional Valve E block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the right valve position. In the left position, port P is connected to port B, while port A is connected to port T. All connections are blocked in neutral position. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of four Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices P-B1 and A-T) and closes the orifices colored yellow (orifices P-A and P-B2). As a result, the openings of the orifices are computed as follows:



$$h_{PA} = h_{PA0} - x$$

$$h_{PB1} = h_{PB10} + x$$

$$h_{PB2} = h_{PB20} - x$$

$$h_{AT} = h_{AT0} + x$$

where

$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{PB1}$	Orifice opening for the Variable Orifice P-B1 block
$h_{PB2}$	Orifice opening for the Variable Orifice P-B2 block
$h_{AT}$	Orifice opening for the Variable Orifice A-T block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{PB10}$	Initial opening for the Variable Orifice P-B1 block
$h_{PB20}$	Initial opening for the Variable Orifice P-B2 block
$h_{AT0}$	Initial opening for the Variable Orifice A-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-163
- “Valve Opening Offsets Tab” on page 1-166

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

**Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to By maximum area and opening.

**Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to By maximum area and opening.

**Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to By area vs. opening table, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to By pressure-flow characteristic, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

**Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to By area vs. opening table.

**Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

**Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

**Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## Valve Opening Offsets Tab

### Between ports P and A

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports A and T

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports P and B1

Orifice opening of the **P-B1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

### Between ports P and B2

Orifice opening of the **P-B2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

## Ports

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## Version History

Introduced in R2009b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## **See Also**

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve F

Configuration F of hydraulic continuous 4-way directional valve

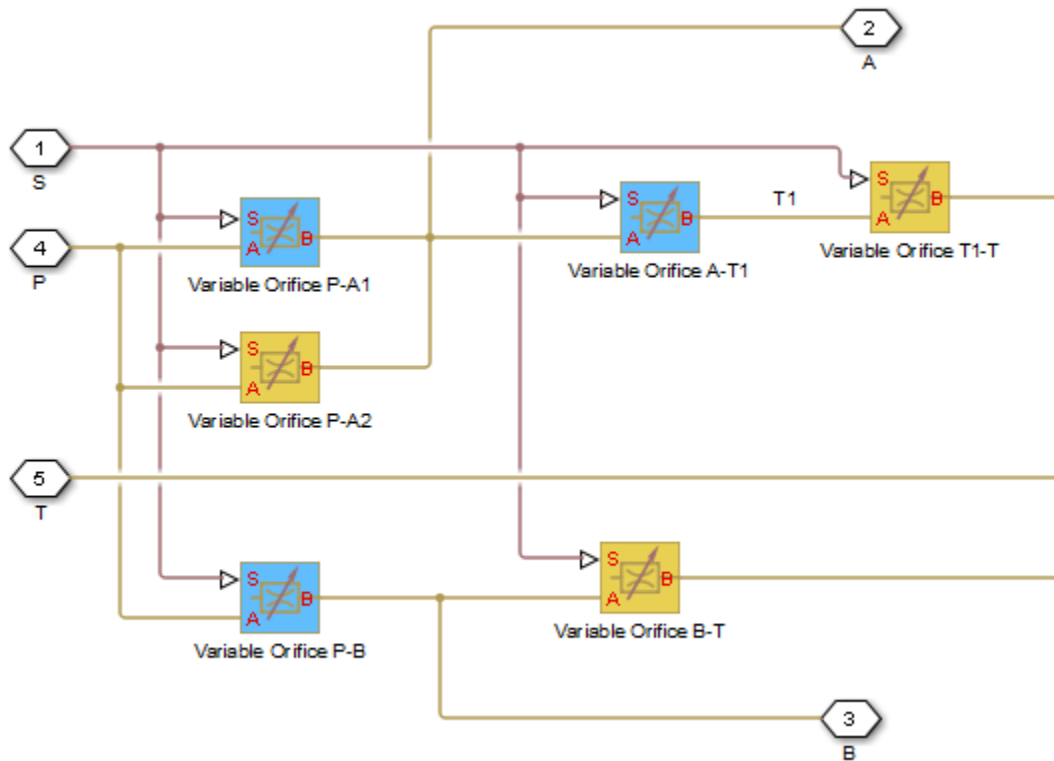


### Library

Directional Valves

### Description

The 4-Way Directional Valve F block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the left valve position. In the right position, port P is connected to port A, while port B is connected to port T. In neutral position, ports A and B are connected to port T. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices P-A1, A-T1, and P-B) and closes the orifices colored yellow (orifices P-A2, B-T, and T1-T). As a result, the openings of the orifices are computed as follows:

$$h_{PA1} = h_{PA10} + x$$

$$h_{PA2} = h_{PA20} - x$$

$$h_{AT1} = h_{AT10} + x$$

$$h_{T1T} = h_{T1T0} - x$$

$$h_{PB} = h_{PB0} + x$$

$$h_{BT} = h_{BT0} - x$$

where

$h_{PA1}$	Orifice opening for the Variable Orifice P-A1 block
$h_{PA2}$	Orifice opening for the Variable Orifice P-A2 block
$h_{AT1}$	Orifice opening for the Variable Orifice A-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block

$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{PA10}$	Initial opening for the Variable Orifice P-A1 block
$h_{PA20}$	Initial opening for the Variable Orifice P-A2 block
$h_{AT10}$	Initial opening for the Variable Orifice A-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-170
- “Valve Opening Offsets Tab” on page 1-172

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

#### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### Valve maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### Valve opening vector, $s$

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear



interpolation, at least three values for smooth interpolation. The default values, in meters, are [-0.002 0 0.002 0.005 0.015]. If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

#### Valve passage area vector

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $m^2$ , are [1e-09 2.0352e-07 4.0736e-05 0.00011438 0.00034356]. This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

#### Pressure differential vector, dp

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are [-1e+07 -5e+06 -2e+06 2e+06 5e+06 1e+07]. This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### Volumetric flow rate table, q(s,dp)

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $m^3/s$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (**By area vs. opening table**) or surface (**By pressure-flow characteristic**) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

#### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.

- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### **Flow discharge coefficient**

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### **Laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### **Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### **Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## **Valve Opening Offsets Tab**

### **Between ports P and A1**

Orifice opening of the **P-A1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of 0 corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

### **Between ports P and A2**

Orifice opening of the **P-A2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of 0 corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

### **Between ports A and T1**

Orifice opening of the **A-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of 0 corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3$  m.

**Between ports P and B**

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3$  m.

**Between ports B and T**

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3$  m.

**Ports**

The block has the following ports:

**P**

Hydraulic conserving port associated with the pressure supply line inlet.

**T**

Hydraulic conserving port associated with the return line connection.

**A**

Hydraulic conserving port associated with the actuator connection port.

**B**

Hydraulic conserving port associated with the actuator connection port.

**S**

Physical signal port to control spool displacement.

**Version History**

**Introduced in R2009b**

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve G

Configuration G of hydraulic continuous 4-way directional valve

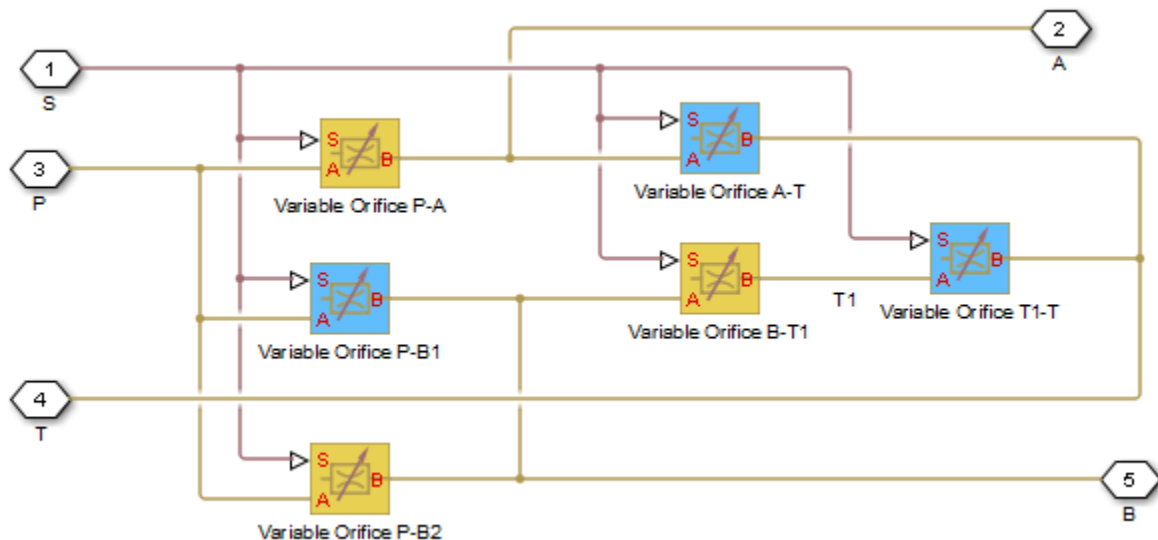


### Library

Directional Valves

### Description

The 4-Way Directional Valve G block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the right valve position. In the left position, port P is connected to port B, while port A is connected to port T. In neutral position, ports A and B are connected to port T. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices P-B1, A-T, and T1-T) and closes the orifices colored yellow (orifices P-A, B-T1, and P-B2). As a result, the openings of the orifices are computed as follows:

$$h_{PB1} = h_{PB10} + x$$

$$h_{PB2} = h_{PB20} - x$$

$$h_{BT1} = h_{BT10} - x$$

$$h_{T1T} = h_{T1T0} + x$$

$$h_{PA} = h_{PA0} - x$$

$$h_{AT} = h_{AT0} + x$$

where

$h_{PB1}$	Orifice opening for the Variable Orifice P-B1 block
$h_{PB2}$	Orifice opening for the Variable Orifice P-B2 block
$h_{BT1}$	Orifice opening for the Variable Orifice B-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{AT}$	Orifice opening for the Variable Orifice A-T block
$h_{PB10}$	Initial opening for the Variable Orifice P-B1 block
$h_{PB20}$	Initial opening for the Variable Orifice P-B2 block
$h_{BT10}$	Initial opening for the Variable Orifice B-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{AT0}$	Initial opening for the Variable Orifice A-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-175
- “Valve Opening Offsets Tab” on page 1-178

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- By maximum area and opening — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.

- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve opening vector, *s*

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

### Valve passage area vector

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

### Pressure differential vector, *dp*

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

### Volumetric flow rate table, *q(s,dp)*

Specify the flow rates as an *m*-by-*n* matrix, where *m* is the number of valve openings and *n* is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to `By pressure-flow characteristic`.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (`By area vs. opening table`) or surface (`By pressure-flow characteristic`) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is `0.7`.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is `0.999`. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is `12`, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system

from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### **Valve Opening Offsets Tab**

#### **Between ports P and B1**

Orifice opening of the **P-B1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### **Between ports P and B2**

Orifice opening of the **P-B2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### **Between ports B and T1**

Orifice opening of the **B-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### **Between ports P and A**

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### **Between ports A and T**

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

## **Ports**

The block has the following ports:

**P**

Hydraulic conserving port associated with the pressure supply line inlet.

**T**

Hydraulic conserving port associated with the return line connection.

**A**

Hydraulic conserving port associated with the actuator connection port.

**B**

Hydraulic conserving port associated with the actuator connection port.

**S**

Physical signal port to control spool displacement.



## Version History

Introduced in R2009b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve H | 4-Way Directional Valve K | 6-Way Directional Valve A

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve H

Configuration H of hydraulic continuous 4-way directional valve

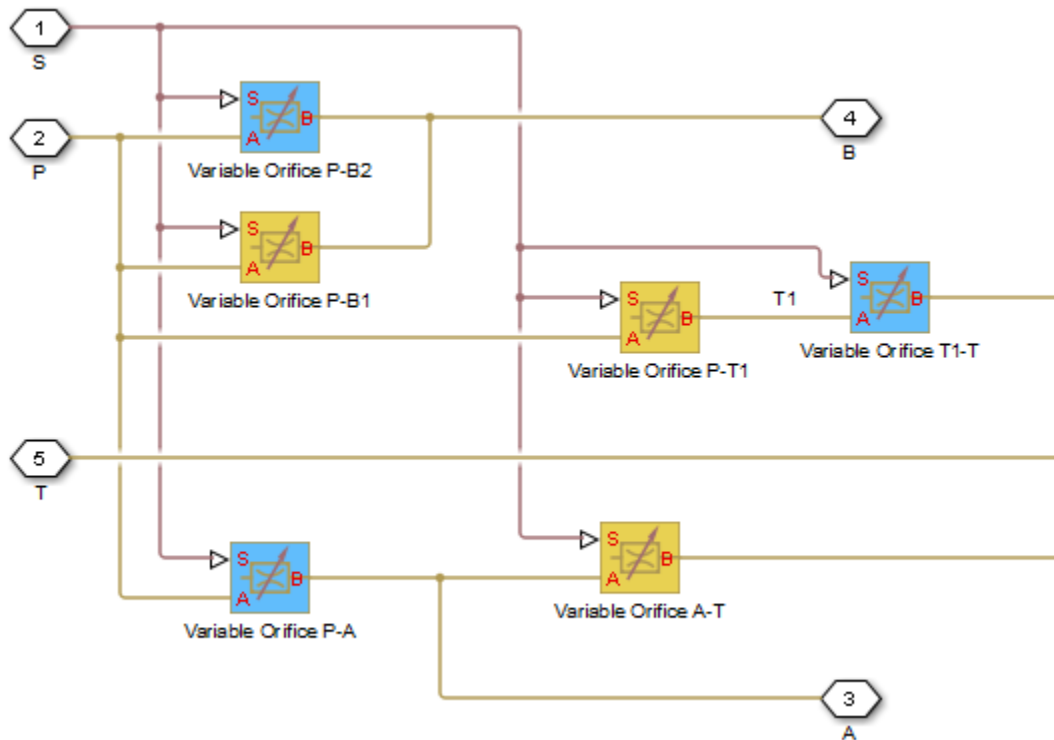


### Library

Directional Valves

### Description

The 4-Way Directional Valve H block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the left valve position. In the right position, port P is connected to port B, while port A is connected to port T. In neutral position, port P is connected to port T to unload the pump. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices P-B2, P-A, and T1-T) and closes the orifices colored yellow (orifices P-B1, P-T1, and A-T). As a result, the openings of the orifices are computed as follows:

$$h_{PB1} = h_{PB10} - x$$

$$h_{PB2} = h_{PB20} + x$$

$$h_{PT1} = h_{PT10} - x$$

$$h_{T1T} = h_{T1T0} + x$$

$$h_{PA} = h_{PA0} + x$$

$$h_{AT} = h_{AT0} - x$$

where

$h_{PB1}$	Orifice opening for the Variable Orifice P-B1 block
$h_{PB2}$	Orifice opening for the Variable Orifice P-B2 block
$h_{PT1}$	Orifice opening for the Variable Orifice P-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{AT}$	Orifice opening for the Variable Orifice A-T block
$h_{PB10}$	Initial opening for the Variable Orifice P-B1 block
$h_{PB20}$	Initial opening for the Variable Orifice P-B2 block
$h_{PT10}$	Initial opening for the Variable Orifice P-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{AT0}$	Initial opening for the Variable Orifice A-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-181
- “Valve Opening Offsets Tab” on page 1-184

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

#### **Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

#### **Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

#### **Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### **Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with

sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Valve Opening Offsets Tab****Between ports P and B1**

Orifice opening of the **P-B1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and B2**

Orifice opening of the **P-B2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and T1**

Orifice opening of the **P-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports P and A**

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports A and T**

Orifice opening of the **A-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

**B**

Hydraulic conserving port associated with the actuator connection port.

**S**

Physical signal port to control spool displacement.

## **Version History**

**Introduced in R2009b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve K | 6-Way Directional Valve A

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way Directional Valve K

Configuration K of hydraulic continuous 4-way directional valve

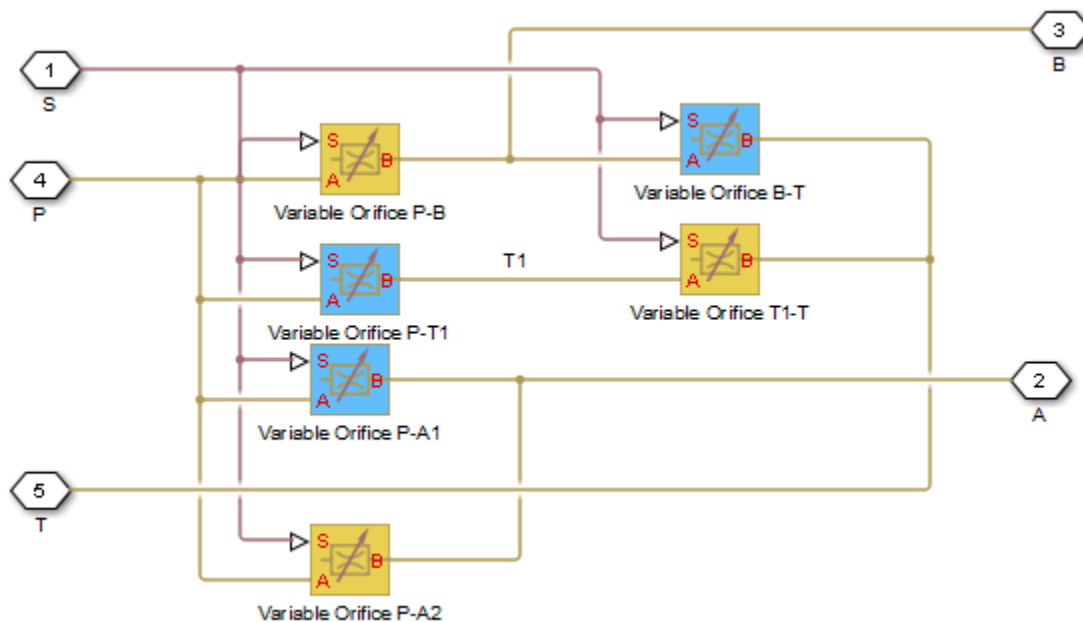


### Library

Directional Valves

### Description

The 4-Way Directional Valve K block simulates a configuration of hydraulic continuous 4-way directional valve. Ports A and B are connected to port P in the right valve position. In the left position, port P is connected to port B, while port A is connected to port T. In neutral position, port P is connected to port T to unload the pump. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All Variable Orifice blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that



positive signal at port S opens the orifices colored blue in the block diagram (orifices P-A1, P-T1, and B-T) and closes the orifices colored yellow (orifices P-A2, P-B, and T1-T). As a result, the openings of the orifices are computed as follows:

$$h_{PA1} = h_{PA10} + x$$

$$h_{PA2} = h_{PA20} - x$$

$$h_{PT1} = h_{PT10} + x$$

$$h_{T1T} = h_{T1T0} - x$$

$$h_{PB} = h_{PB0} - x$$

$$h_{BT} = h_{BT0} + x$$

where

$h_{PA1}$	Orifice opening for the Variable Orifice P-A1 block
$h_{PA2}$	Orifice opening for the Variable Orifice P-A2 block
$h_{PT1}$	Orifice opening for the Variable Orifice P-T1 block
$h_{T1T}$	Orifice opening for the Variable Orifice T1-T block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block
$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{PA10}$	Initial opening for the Variable Orifice P-A1 block
$h_{PA20}$	Initial opening for the Variable Orifice P-A2 block
$h_{PT10}$	Initial opening for the Variable Orifice P-T1 block
$h_{T1T0}$	Initial opening for the Variable Orifice T1-T block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-187
- “Valve Opening Offsets Tab” on page 1-190

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- By maximum area and opening — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member

displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.

- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Valve opening vector, *s*

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

### Valve passage area vector

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

### Pressure differential vector, *dp*

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

### Volumetric flow rate table, *q(s,dp)*

Specify the flow rates as an *m*-by-*n* matrix, where *m* is the number of valve openings and *n* is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
```

```
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Valve Opening Offsets Tab****Between ports P and A1**

Orifice opening of the **P-A1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and A2**

Orifice opening of the **P-A2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports P and T1**

Orifice opening of the **P-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports T1 and T**

Orifice opening of the **T1-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Between ports P and B**

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

**Between ports B and T**

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

**Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the return line connection.

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

S

Physical signal port to control spool displacement.

## **Version History**

**Introduced in R2009b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 6-Way Directional Valve A

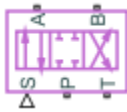
## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 4-Way 3-Position Directional Valve (G)

Controlled valve with four ports in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Directional Control Valves

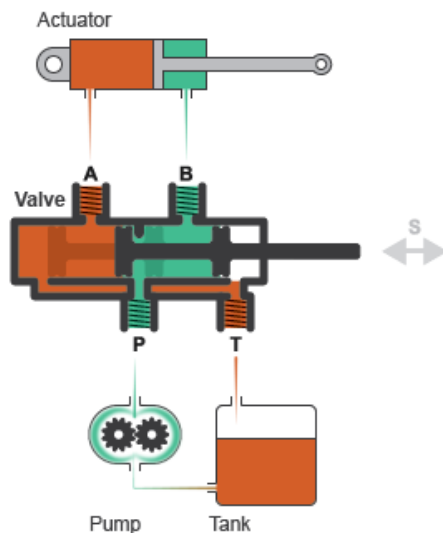


### Description

The 4-Way 3-Position Directional Valve (G) block represents a valve with four gas ports (**P**, **A**, **B**, and **T**) and flow paths between **P-A** and **A-T** and between **P-B** and **B-T**. The paths each run through an orifice of variable width. The input signal specified at port **S** controls the position of the spool. The valve closes when the spool covers the orifice opening.

In a representative system, the **P** port connects to the pump, the **T** port connects to the tank, and the **A** and **B** ports connect to a double-sided actuator. Opening the **P-A** and **B-T** flow paths allows the pump to pressurize one side of the actuator and the tank to relieve the other. The actuator shaft translates to extend in some systems and retract in others. Opening the **P-B** and **A-T** flow paths flips the pressurized and relieved sides of the actuator so that the shaft can translate in reverse.

This image shows a common use for a four-way, three-position directional valve in a physical system:



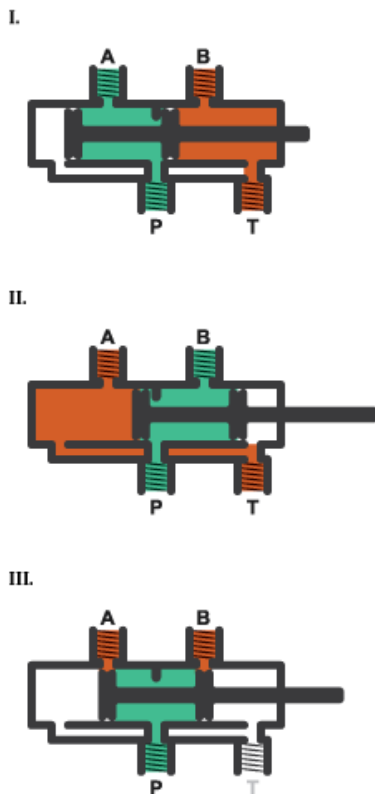
The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

## Valve Positions

The valve is continuously variable and it shifts smoothly between one normal and two working positions.

When the instantaneous displacement of the spool at port **S** is zero, the valve reverts to the normal position where it is no longer operating. Unless the lands of the spool are at an offset to their orifices, the valve is fully closed. The working positions are the positions the valve moves to when the spool is maximally displaced from its normal position. That displacement is positive in one case and negative in the other.

Image **I** shows a valve where the displacement is positive, the **P-A** and **B-T** orifices are fully open, and the **P-B** and **A-T** orifices are fully closed. Image **II** shows a valve where the displacement is negative, the **P-A** and **B-T** orifices are fully closed, and the **P-B** and **A-T** orifices are fully open. Image **III** shows a valve where the spool is in the neutral position and all the orifices are closed.



The spool displacement that puts the valve in its working position depends on the offsets of the lands on the spool. The parameters in the **Valve Opening Fraction Offsets** section specify the block constants for the spool displacements of the ports.

## Orifice Opening Fractions

Between valve positions, the opening of an orifice depends on where the land of the spool is, relative to the rim. This distance is the orifice opening, and the block normalizes this distance so that its value is a fraction of the maximum distance at which the orifice is fully open. The normalized variable is the orifice opening fraction.

The orifice opening fractions range from -1 when the valve is in the position shown in image **I** to +1 when the valve is in the position shown in image **II**.

The block calculates the opening fractions from the spool displacement and opening fraction offset. The displacement and offset are unitless fractions of the maximum land-orifice distance.

The opening fraction of the **P-A** orifice is:

$$h_{\mathbf{PA}} = H_{\mathbf{PA}} + x.$$

The opening fraction of the **B-T** orifice is:

$$h_{\mathbf{BT}} = H_{\mathbf{BT}} + x.$$

The opening fraction of the **A-T** orifice is:

$$h_{\mathbf{AT}} = H_{\mathbf{AT}} - x.$$

The opening fraction of the **P-B** orifice is:

$$h_{\mathbf{PB}} = H_{\mathbf{PB}} - x.$$

In the equations:

- $h$  is the opening fraction for the orifice. If the calculation returns a value outside of the range 0 - 1, the block uses the nearest limit.
- $H$  is the opening fraction offset for the orifice. The parameters in the **Valve Opening Fraction Offsets** section specify the opening fraction offsets. To allow for unusual valve configurations, the block imposes no limit on their values, although they are typically between -1 and +1.
- $x$  is the normalized instantaneous displacement of the spool, specified by a physical signal at port **S**. To compensate for extreme opening fraction offsets, there is no limit on the signal value. The value is typically between -1 and +1.

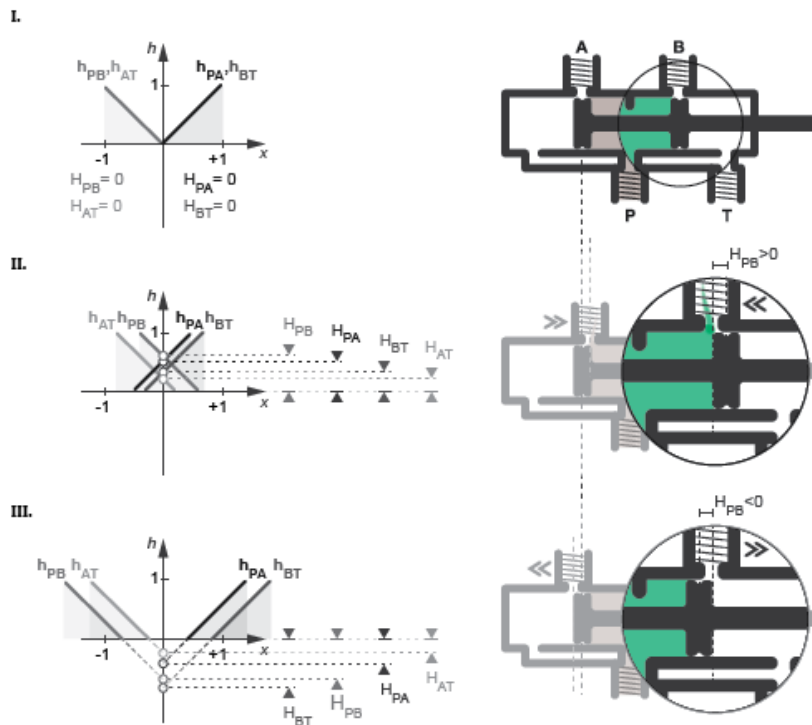
### Opening Fraction Offsets

By default, the valve is fully closed when its control displacement is zero. In this state, the valve is zero-lapped.

You can offset the lands of the spool to model an underlapped or overlapped valve. Underlapped valves are partially open in the normal position. Overlapped valves are fully closed slightly beyond the normal position. The figure shows how the orifice opening fractions vary with the instantaneous spool displacement:

- Image **I**: A zero-lapped valve. The opening fraction offsets are all zero. When the valve is in the normal position, the lands of the spool completely cover all four orifices.
- Image **II**: An underlapped valve. The **P-A** and **B-T** opening fraction offsets are positive and the **P-B** and the **A-T** opening fraction offsets are negative. When the valve is in the normal position, the lands of the spool partially cover the four orifices.
- Image **III**: An overlapped valve. The **P-A** and **B-T** opening fraction offsets are negative and the **P-B** and the **A-T** opening fraction offsets are positive. The control member completely covers all orifices not only in the normal position but over a small region of spool displacements around it.





### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

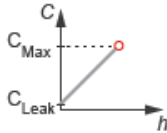
- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential. [2][3]
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*. [1]
- **Orifice area** — The size of the flow restriction determines the block parameterization. [4]

### Opening Characteristics

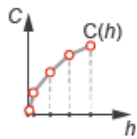
The flow characteristic relates the opening of the valve to the input that produces it, which is often the spool travel. The block expresses the opening as a sonic conductance, flow coefficient, or restriction area, depending on the setting of the **Valve parametrization** parameter. The control input is the orifice opening fraction, a function of the spool displacement specified at port S.

The flow characteristic is normally given at steady state, with the inlet at a constant, carefully controlled pressure. The flow characteristic depends only on the valve and can be linear or nonlinear. To capture the flow characteristics, use the **Opening characteristic** parameter:

- **Linear** — The measure of flow capacity is a linear function of the orifice opening fraction. As the opening fraction rises from 0 to 1, the measure of flow capacity scales from the specified minimum to the specified maximum.



- **Tabulated** — The measure of flow capacity is a general function, which can be linear or nonlinear, of the orifice opening fraction. The function is specified in tabulated form, with the independent variable specified by the **Opening fraction vector**.



### Numerical Smoothing

When the **Opening characteristic** parameter is Linear, and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the orifice opening fraction. Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Leakage Flow

The leakage flow ensures that no section of a fluid network becomes isolated. Isolated fluid sections can reduce the numerical robustness of the model, slow the rate of simulation and, in some cases, cause the simulation to fail. The **Leakage flow fraction** parameter represents the leakage flow area in the block as a small number greater than zero.

### Composite Structure

This block is a composite component comprising four instances of the Orifice (G) block connected to ports **P**, **A**, **B**, **T**, and **S**. Refer to the Orifice (G) block for more detail on the valve parameterizations and block calculations.

### Assumptions and Limitations

- The Sonic conductance setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the Orifice area parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Input

#### **S – Valve control signal, unitless**

physical signal

Instantaneous displacement of the control member against its normal unactuated position, specified as a physical signal. The block normalizes the displacement against the maximum position of the control member that required to open the orifice fully. The signal is unitless and its instantaneous value is typically in the range between -1 and +1.

### Conserving

#### **A – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **B – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **P – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **T – Valve opening**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

## Parameters

### **Valve parameterization – Parameterization used to specify flow characteristics of orifice**

`Cv flow coefficient (default)` | `Kv flow coefficient` | `Sonic conductance` | `Orifice area`

Method to calculate the mass flow rate.

- `Cv flow coefficient` – The flow coefficient  $C_v$  determines the block parameterization.
- `Kv flow coefficient` – The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- `Sonic conductance` – The sonic conductance of the resistive element at steady state determines the block parameterization.
- `Orifice area` – The size of the flow restriction determines the block parametrization.

### **Opening characteristic – Method to calculate the opening characteristics of the valve**

`Linear (default)` | `Tabulated`

Method the block uses to calculate the opening area of the valve. The linear setting treats the opening area as a linear function of the orifice opening fraction. The tabulated setting allows for a general, nonlinear relationship you can specify in tabulated form.

### Opening fraction vector — Control signal values at which to specify tabulated parameter data

0 : 0.2 : 1 (default) | vector of positive numbers

Vector of control signal values at which to specify the chosen measure of flow capacity: **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector**. The control signal is between 0 and 1, with each value corresponding to an opening fraction of the resistive element. The greater the value, the greater the opening and easier the flow.

The opening fractions must increase monotonically across the vector from left to right. The size of this vector must be the same as the **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector** parameter.

#### Dependencies

To enable this parameter, set **Opening characteristic** to Tabulated.

### Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Linear.

### xT pressure differential ratio factor at choked flow — Ratio of pressure differentials

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

### Leakage flow fraction — Ratio of flow rates

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

#### Dependencies

To enable this parameter, set **Opening characteristic** to Linear.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Cv flow coefficient vector – Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum Kv flow coefficient – Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector – Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers

Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum sonic conductance – Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference density — ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12] 1/(bar\*s) (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Critical pressure ratio vector – Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Maximum orifice area – Flow area corresponding to maximally open component**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Linear`.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Orifice area vector – Vector of orifice opening area values**

[1e-10, 2e-05, 4e-05, 6e-05, 8e-05, .0001] m<sup>2</sup> (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Tabulated`.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A, B, P, and T — Area normal to the flow path at the valve ports**

0.01 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the flow path at the valve ports. The ports are assumed to be of the same size. The flow area specified here should ideally match those of the inlets of adjoining components.

**Valve Opening Fraction Offsets****Between Ports P and A — Opening fraction offset for the P-A orifice**

0 (default) | unitless scalar

Opening fraction of the **P-A** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **P-A**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

**Between Ports B and T — Opening fraction offset for the B-T orifice**

0 (default) | unitless scalar

Opening fraction of the **B-T** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **B-T**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

**Between Ports P and B — Opening fraction offset for the P-B orifice**

0 (default) | unitless scalar

Opening fraction of the **P-B** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **P-B**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

**Between Ports A and T — Opening fraction offset for the A-T orifice**

0 (default) | unitless scalar

Opening fraction of the **A-T** orifice when the value of the input signal **S** is zero. The valve is then in the normal position. The opening fraction measures the distance of a land of the spool to its appointed orifice, here **A-T**, normalized by the maximum such distance. It is unitless and generally between 0 and 1.

## Version History

Introduced in R2018b

**Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:



- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow, Kv coefficient (SI) at leakage flow, Sonic conductance at leakage flow,** and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

### Updated block name

The title of the 4-Way Directional Valve (G) block changed to 4-Way 3-Position Directional Valve (G).

## References

- [1] ISO 6358-3. "Pneumatic fluid power - Determination of flow-rate characteristics of components using compressible fluids - Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves - Part 2-3: Flow capacity - Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves - Part 2-1: Flow capacity - Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

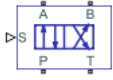
## See Also

Orifice (G) | 2-Way Directional Valve (G) | 3-Way Directional Valve (G)

## 4-Way 2-Position Directional Valve (IL)

4-way, 2-position directional valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves

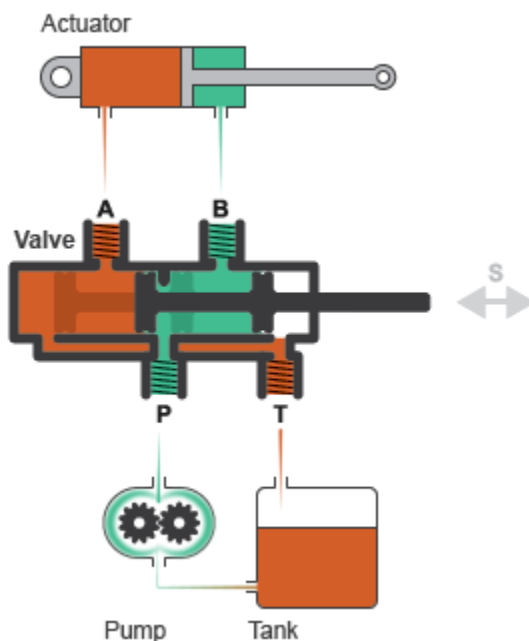


### Description

The 4-Way 2-Position Directional Valve (IL) block models a valve with four openings in an isothermal liquid network, typically between an actuator, pump, and tank. The valve operation is controlled by a single spool displaced according to the signal at port **S**. You can set the baseline configuration of your valve by specifying the orifices that are open when the spool moves in the positive direction and negative directions in the **Positive spool position open connections** and **Negative spool position open connections** parameters, respectively.

You can set the model for valve opening in the **Orifice parameterization** parameter as a linear relationship or function of user-provided data, which can be applied to one or all flow paths in the valve.

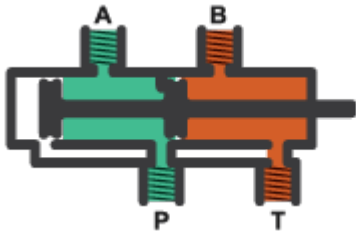
In some configurations, this valve resembles a 3-way valve. To set additional flow paths when the spool is in the neutral position, see the 4-Way 3-Position Directional Valve (IL) block.



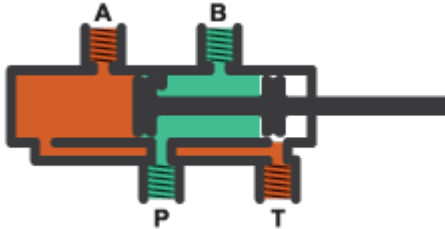
### Example Valve Setup

In this configuration, **Negative spool position open connections** is set to P-A and B-T. When the signal at port **S** moves the spool to a negative position, the paths between ports **P** and **A** and between

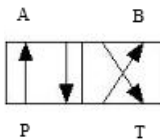
ports **B** and **T** are open to flow. The paths between ports **P** and **B** and ports **A** and **T** are closed to flow:



In this configuration, **Positive spool position open connections** is set to P-B and A-T. When the signal at port **S** moves the spool to a positive position, the paths between ports **P** and **B** and between ports **A** and **T** are open to flow and the paths between ports **P** and **A** and between ports **B** and **T** are closed:



Schematically, this configuration is:



The left-hand side corresponds to the positive position and the right-hand side corresponds to the negative position. The valve transitions through positions in the neutral mid-section.

### Spool Displacement and Valve Configuration

The *spool stroke* is the amount of spool travel an orifice takes to fully open from a closed position and is defined for each orifice selected on the **Valve Configuration** tab. The table below shows how the stroke is calculated in accordance with the valve orifice parameterization and flow path characteristics.

**Spool Stroke Based on Parameterization and Flow Path**

<b>Orifice Parameterization</b>	<b>Identical for All Flow Paths</b>	<b>Different for Each Flow Path</b>
Linear - Area vs. spool travel	Defined by the <b>Spool travel between closed and open orifice</b> parameter	Defined by the Spool travel between closed and open orifice parameter, for each orifice
Tabulated data - Area vs. spool travel	The difference between the first and last element of the <b>Spool travel vector</b> parameter	The difference between the first and last element of the spool travel vector parameter for each orifice
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop	The difference between the first and last element of the <b>Spool travel vector, ds</b> parameter	The difference between the first and last element of the spool travel vector, ds parameter for each orifice

To see the orientation of all valve orifices, see the “Visualize Orifice Openings” on page 1-253 section.

The direction of spool movement signaled at port **S** depends on the spool stroke and the orifice orientation:

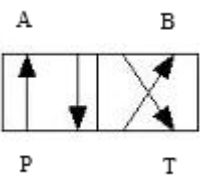
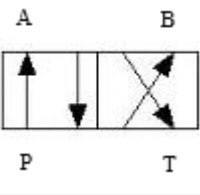
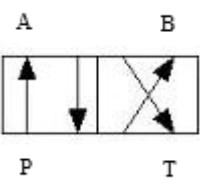
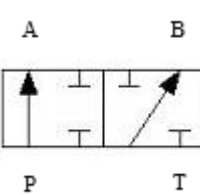
**Orifice Definition and Spool Travel Direction**

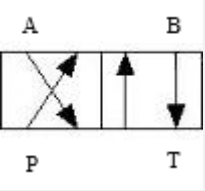
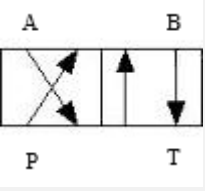
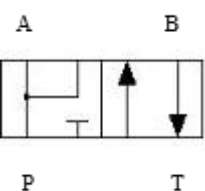
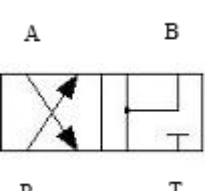
<b>Spool Position when Orifice is Open</b>	<b>Spool Travel, <math>\Delta S</math></b>
Always closed (orifice is not selected in any spool position configuration)	N/A
Always open (orifice is selected in positive, neutral, and negative spool position configurations)	N/A
Negative	$S_{\text{orifice\_max}} + \text{spool stroke} - \mathbf{S}$
Positive	$S_{\text{orifice\_max}} + \text{spool stroke} + \mathbf{S}$

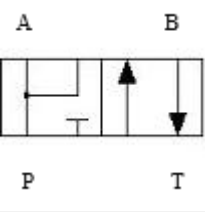
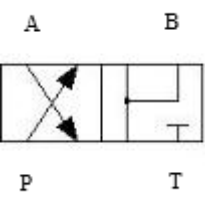
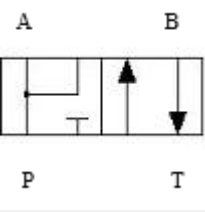
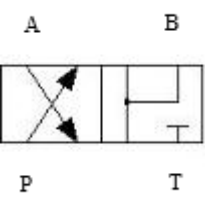
Where  $S_{\text{orifice\_max}}$  is the spool position at the maximum orifice area defined for each orifice.

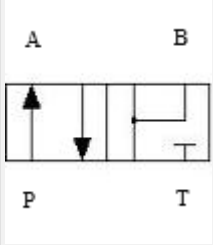
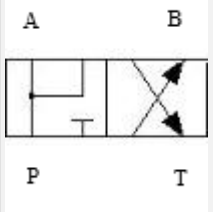
The possible configurations of the 4-Way 2-Position Directional Valve (IL) block are shown below.

## 4-Way 2-Position Directional Valve Configuration

Configuration	Parameter Values
 <p data-bbox="240 590 542 653">All four paths are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
 <p data-bbox="240 982 610 1045">All four paths are open during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; B-T spool stroke</li> </ul>
 <p data-bbox="240 1375 607 1438">A-T and B-T are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
 <p data-bbox="240 1791 607 1854">P-A and P-B are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A only</li> <li>• <b>Negative spool position open connections:</b> P-B only</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> </ul>

Configuration	Parameter Values
 <p>P-B and B-T are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> </ul>
 <p>P-A and A-T are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>
 <p>P-A, P-B, and B-T are open during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> = any value</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>
 <p>P-A, A-T, and B-T are open during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; -P-A spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>

Configuration	Parameter Values
 <p data-bbox="245 562 607 653">P-A and P-B are closed during transition. A-T is always closed.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> </ul>
 <p data-bbox="245 934 574 991">All paths are closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> </ul>
 <p data-bbox="245 1276 607 1333">A-T is open during transition. P-A is closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> = any value</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>
 <p data-bbox="245 1640 607 1730">B-T is open during transition. P-B is closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>

Configuration	Parameter Values
 <p>P-A is closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
 <p>P-B is closed during transition.</p>	<ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> </ul>

### Valve Orifice Parameterizations

The **Orifice parameterization** parameter sets the model for the open area or volumetric flow rate through one or all of the valve orifices. If you set **Area characteristics** to `Identical` for all flow paths, the block applies the same data for all flow paths; otherwise, individual parameterizations are applied for the `Different` for all flow paths setting. You can model valve opening in three ways:

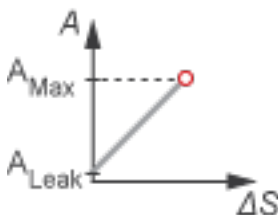
- Linear - area vs. spool travel

The opening area is a linear function of the spool position received as a signal at port **S**:

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where:

- $\Delta S$  is the spool travel defined in Orifice Definition and Spool Travel Direction.
- $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.
- $A_{max}$  is the **Maximum orifice area**.
- $A_{leak}$  is the **Leakage area**.

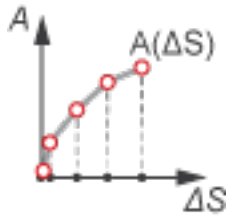




When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

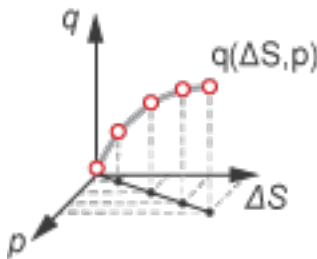
- Tabulated data - Area vs. spool travel

Provide spool travel vectors for your system or for individual flow paths between ports **P**, **A**, **B**, and **T**. This data will be used to calculate the relationship between the orifice area and spool displacement. Interpolation is used to determine the opening area between given data points.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the opening area vector, respectively.



- Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Provide spool travel and pressure drop vectors and a dependent, 2-D volumetric flow rate array. Interpolation is used to determine flow rate between given data points. The mass flow rate is the product of the volumetric flow rate and the local density.



### Visualize Orifice Openings

To visualize spool offsets and maximum displacement, right-click on the block and select **Fluids > Plot Valve Characteristics**. The plot shows the orifices selected in the **Valve Configuration** tab settings. The axes are set by the orifice parameterization selection and are either:

- Orifice Area vs. Spool Position
- Volumetric Flow Rate vs. Spool Position, queried at a specific pressure differential

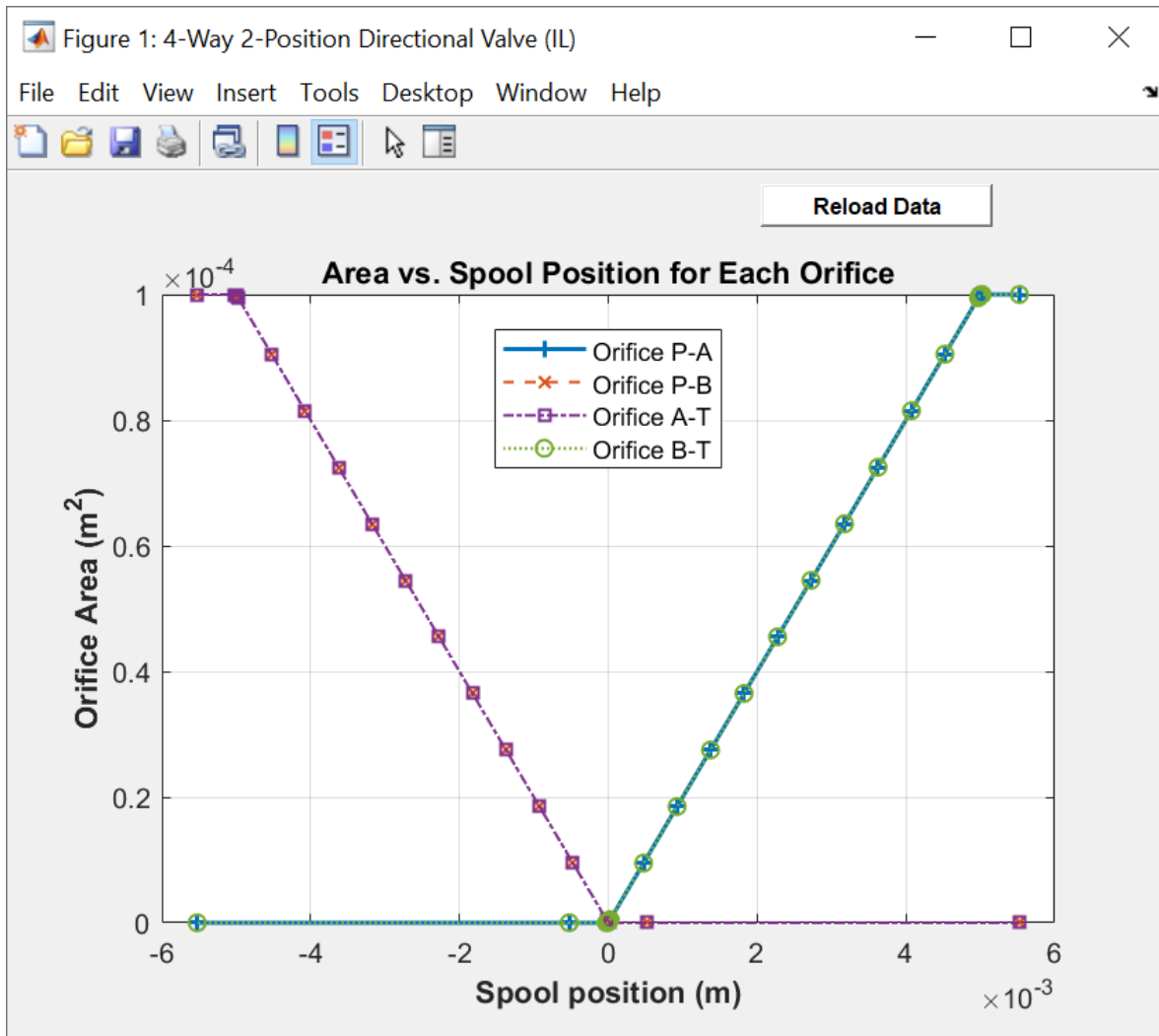
When the positive and negative settings in the **Valve Configuration** tab feature the same orifice, the orifice opening is displayed as a constant.

Each time you modify the block settings, click **Reload Data** on the figure window.

The image below shows the valve default configuration. On the **Valve Configuration** tab:

- **Positive spool position open connections** is set to P-A and B-T.
- **Negative spool position open connections** is set to P-B and A-T.

All other spool positions are at the default values.



### Example Spool Position Visualization

#### Faults

When faults are enabled, the valve open area becomes stuck at a specified spool position in response to one of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **Tr**.

Four fault options are available in the **Spool position when faulted** parameter:

- **Positive** — The spool position freezes in the positive position, opening the **Positive spool position open connections** flow paths to their maximum value. The flow paths that are only open in the **Negative spool position open connections** and **Neutral spool position open connections** are closed.
- **Negative** — The spool position freezes in the negative position, opening the **Negative spool position open connections** flow paths to their maximum value. The flow paths that are only

open in the **Positive spool position open connections** and **Neutral spool position open connections** are closed.

- **Maintain last value** — The valve freezes at the spool position when the trigger occurs.

Due to numerical smoothing at the extremes of the valve area, in the linear parameterization, the minimum area applied is larger than the **Leakage area**, and the maximum is smaller than the **Maximum orifice area**, in proportion to the **Smoothing factor** value.

Once triggered, the valve remains at the faulted area for the rest of the simulation.

### Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

---

**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see "List of Pre-Parameterized Components".

## Ports

### Conserving

#### **A — Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

#### **B — Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

#### **P — Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

**T – Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

**Input****S – Spool displacement, m**

physical signal

Spool displacement, in m, specified as a physical signal.

**Tr – External fault trigger**

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

**Dependencies**

This port is visible when **Enable faults** is set to On and **Fault trigger** is set to External.

**Parameters****Valve Configuration****Positive spool position open connections – Flow paths open when the spool is in a positive position**

P-A and B-T (default) | P-A and P-B | P-B and A-T | P-A only | P-B only

Flow paths open when the spool is in a positive position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Negative spool position open connections – Flow paths open when the spool moves in the negative direction**

P-B and A-T (default) | P-A and B-T | P-A and P-B | P-A only | P-B only

Flow paths open when the spool moves in the negative direction. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**.

**Model Parameterization****Area characteristics – Flow equations for orifices**

Identical for all flow paths (default) | Different for each flow path

Applies uniform or individual flow equations for the valve orifice area. **Identical for all flow paths** uses the same orifice and spool geometries, flow rates, pressure, and area vectors for all valve orifices. When using **Different for each flow path**, these parameters are specified individually for each orifice. In both cases, orifices **A**, **B**, **P**, and **T** have the same cross-sectional areas, discharge coefficients, and Reynolds numbers in the **Linear - Area vs. spool travel** and **Tabulated data - Area vs. spool travel** parameterizations. The same **Orifice parameterization** is applied to all flow paths.

**Orifice parameterization — Method of calculating opening area**

Linear area vs. spool travel (default) | Tabulated data - Area vs. spool travel |  
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Method of calculating the valve opening area. In the tabulated data parameterizations, you can provide your own valve area and spool travel data for nonlinear valve opening profiles, or you can provide data in terms of volumetric flow rate, spool travel, and pressure drop over the flow path.

**Spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of each orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Leakage area — Open area when an orifice is fully closed**

1e-9 m<sup>2</sup> (default) | positive scalar

Open area when an orifice is fully closed. Any area smaller than this value is maintained at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - Area vs. spool travel.

**Spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**Orifice area vector — Vector of valve opening areas**

[1e-09, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **Spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

#### Spool travel vector, **ds** – Vector of spool opening distances relative to fully closed position

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### Pressure drop vector, **dp** – Vector of valve pressure drop values

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, ds** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

#### Volumetric flow rate table, **q(ds,dp)** – Array of volumetric flow rates

[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;  
-.00036, .00063, .00081, .00096; .00054, .00094, .0012, .0014;  
-.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **Pressure drop vector, dp** parameter.
- *N* is the number of vector elements in the **Spool travel vector, ds** parameter.

#### Dependencies

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Constant orifice area — Orifice area for identical flow paths**1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to either:

- Linear - area vs. spool travel.
- Tabulated data - Area vs. spool travel

The same orifice must be selected in both of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Negative spool position open connections**

**Constant orifice pressure drop vector — Vector of pressure differential values for identical flow paths**[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

The same orifice must be selected in both of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Negative spool position open connections**

**Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for identical flow paths**[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values for a constant orifice when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

The same orifice must be selected in both of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Negative spool position open connections**

**Cross-sectional area at ports P, T, A and B – Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Maximum cross-sectional areas at the entry and exit ports **P**, **T**, **A**, and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to either:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to either:

- Linear - Area vs. spool travel
- Tabulated data - Area vs. spool travel

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range of [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to `Linear - area vs. spool travel`.

**Pressure recovery – Whether to account for pressure increase in area expansions**

Off (default) | On



Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

#### P-A Orifice

**Spool position at maximum P-A orifice area — Spool offset for fully open P-A orifice**  
 $5e-3$  m (default) | positive scalar

Spool offset from the neutral position for a fully open P-A orifice. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

#### Dependencies

To enable this parameter, set one of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

---

**Note:** This parameter is enabled only when the P-A orifice settings do not appear in both spool position parameters: **Positive spool position open connections** and **Negative spool position open connections**.

---

**P-A spool travel between closed and open orifice — Maximum spool stroke**  
 $0.005$  m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-A maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-A orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-A orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice area vector – Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-A spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice spool travel vector, ds – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-A orifice pressure drop vector, dp** parameter for the 2-D dependent **P-A orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**3** One of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice pressure drop vector,  $dp$  — Vector of pressure drop values**

`[-.1, .3, .5, .7]` MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-A orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-A orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

**1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**3** One of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rate values**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024]` m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **P-A orifice pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **P-A orifice spool travel vector,  $ds$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

##### Positive spool position open connections to:

- P-A and B-T
- P-A and P-B
- P-A only

##### Negative spool position open connections to:

- P-A and B-T
- P-A and P-B
- P-A only

#### P-A constant orifice area — Cross-sectional area for a constant orifice

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive and negative spool positions feature the same orifice.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3 One of the following settings in each parameter:

##### Positive spool position open connections to:

- P-A and B-T
- P-A and P-B
- P-A only

##### Negative spool position open connections to:

- P-A and B-T

- P-A and P-B
- P-A only

**P-A Constant orifice pressure drop vector – Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-A Constant orifice volumetric flow rate vector – Vector of volumetric flow rates for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**P-B Orifice**

**Spool position at maximum P-B orifice area — Spool offset from the neutral position for a fully open P-B orifice**

-5e-3 (default) | positive scalar

Spool offset from the neutral position for a fully open P-B orifice. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

**Dependencies**

To enable this parameter, set one of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

---

**Note:** This parameter is enabled only when the P-B orifice settings do not appear in both spool position parameters: **Positive spool position open connections** and **Negative spool position open connections**.

---

**P-B spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.

- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

or set **Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-B orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-B orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.



- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B orifice area vector — Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-B spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B orifice spool travel vector, ds — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector, dp** parameter for the 2-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B orifice pressure drop vector,  $dp$  — Vector of pressure differential values**

[ -.1, .3, .5, .7 ] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-B orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-B orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rate values**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;$   
 $-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;$   
 $-.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-B orifice pressure drop vector,  $dp$**  parameter.
- *N* is the number of vector elements in the **P-B orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B constant orifice area — Cross-sectional area for a constant orifice**

$1e-4$  m<sup>2</sup> (default) | positive scalar

Orifice area when the positive and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3 One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T

- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**P-B Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**3** One of the following settings in each parameter:

**Positive spool position open connections** to:

- P-B and A-T
- P-A and P-B
- P-B only

**Negative spool position open connections** to:

- P-B and A-T
- P-A and P-B
- P-B only

### A-T Orifice

**Spool position at maximum A-T orifice area — Spool offset from the neutral position for a fully open A-T orifice**

-5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open A-T orifice. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

#### Dependencies

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-B and A-T.
- **Negative spool position open connections** to P-B and A-T.

---

**Note:** This parameter is enabled only when the A-T orifice settings do not appear in both spool position parameters: **Positive spool position open connections** and **Negative spool position open connections**.

---

**A-T spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Negative spool position open connections** to P-B and A-T.

**A-T maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the A-T orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.

3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector,  $ds$  – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by- $n$  vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **A-T orifice pressure drop vector,  $dp$**  parameter for the 2-D dependent **A-T orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T orifice pressure drop vector,  $dp$  – Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-T orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **A-T orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T orifice volumetric flow rate table,  $q(ds, dp)$  — Array of volumetric flow rate values**

[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;  
 -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;  
 -.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **A-T orifice pressure drop vector,  $dp$**  parameter.
- *N* is the number of vector elements in the **A-T orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T constant orifice area — Cross-sectional area for a constant orifice**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **A-T Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.



**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice volumetric flow rate vector – Vector of volumetric flow rate values for a constant orifice**

$[-.0009, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Negative spool position open connections** to P-B and A-T.

**B-T Orifice****Spool position at maximum B-T orifice area – Spool offset from the neutral position for a fully open B-T orifice**

$5e-3$  m (default) | positive scalar

Spool offset from the neutral position for a fully open B-T orifice. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

**Dependencies**

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-A and B-T.
- **Negative spool position open connections** to P-A and B-T.

---

**Note:** This parameter is enabled only when the B-T orifice settings do not appear in both spool position parameters: **Positive spool position open connections** and **Negative spool position open connections**.

---

**B-T spool travel between closed and open orifice – Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T maximum orifice area – Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the B-T orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T orifice spool travel vector – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **B-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T orifice area vector – Vector of valve opening areas**[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **B-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T orifice spool travel vector, ds – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **B-T orifice pressure drop vector, dp** parameter for the 2-D dependent **B-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T orifice pressure drop vector, dp – Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **B-T orifice spool travel vector, ds** parameter for the 2-D dependent **B-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T orifice volumetric flow rate table,  $q(ds, dp)$  — Array of volumetric flow rate values**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m3/s (default) | M-by-N matrix`

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **B-T orifice pressure drop vector,  $dp$**  parameter.
- *N* is the number of vector elements in the **B-T orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T constant orifice area — Cross-sectional orifice area for constant orifices**

`1e-4 m2 (default) | positive scalar`

Orifice area when the positive and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice pressure drop vector – Vector of pressure differential values for a constant orifice**[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice volumetric flow rate vector – Vector of volumetric flow rates for a constant orifice**[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Negative spool position open connections** to P-A and B-T.

**Faults****Enable faults – Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Spool position when faulted** parameter.

**Spool position when faulted – Set faulted characteristics**

Positive (default) | Negative | Maintain last value

Sets the faulted valve spool position. You can choose for the valve to seize when the spool is in the positive position, negative position, or at the position when faulting is triggered.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Fault trigger — External or temporal trigger option**

Temporal (default) | External

Whether a fault trigger occurs due to an external event or at a specified time.

When set to External, port **Tr** is enabled. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.

When set to Temporal, when the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Simulation time for fault event — Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## Version History

Introduced in R2021a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

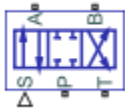
**See Also**

4-Way 3-Position Directional Valve (IL) | 3-Way Directional Valve (IL) | 2-Way Directional Valve (IL)

## 4-Way 3-Position Directional Valve (IL)

4-way, 3-position directional valve in an isothermal liquid system

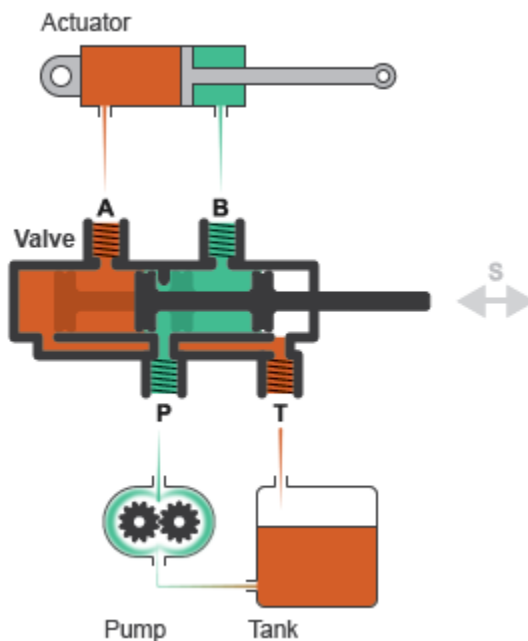
**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



### Description

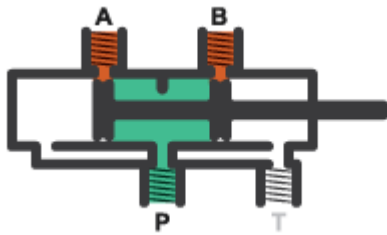
The 4-Way 3-Position Directional Valve (IL) block models a valve with four openings in an isothermal liquid network, typically between an actuator, pump, and tank. The valve operation is controlled by a single spool displaced according to the signal at port **S**. You can set the baseline configuration of your valve by specifying the orifices that are open when the spool is in the neutral position (centered at 0 m) in the **Neutral spool position open connections** parameter, when the spool moves in the positive direction in the **Positive spool position open connections** parameter, and when the spool moves in the negative direction in the **Negative spool position open connections**.

You can set the model for valve opening in the **Orifice parameterization** parameter as a linear relationship or function of user-provided data, which can be applied to one or all flow paths in the valve.

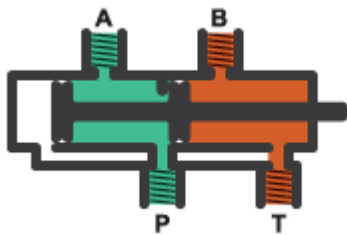


### Example Valve Setup

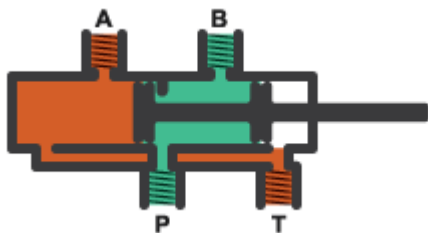
In this example configuration, **Neutral spool position open connections** is set to All closed. When the spool is in the neutral position, all orifices are closed to flow:



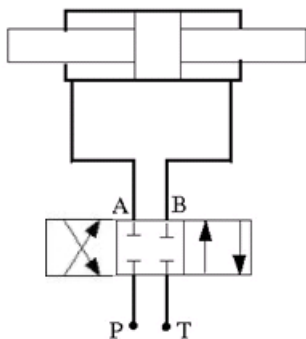
In this configuration, **Negative spool position open connections** is set to P-A and B-T. When the signal at port **S** moves the spool to a negative position, the paths between ports **P** and **A** and between ports **B** and **T** are open to flow. The paths between ports **P** and **B** and ports **A** and **T** are closed to flow:



In this configuration, **Positive spool position open connections** is set to P-B and A-T. When the signal at port **S** moves the spool to a positive position, the paths between ports **P** and **B** and between ports **A** and **T** are open to flow and the paths between ports **P** and **A** and between ports **B** and **T** are closed:



Schematically, this configuration is shown as:





The left-hand side corresponds to the positive position and the right-hand side corresponds to the negative position.

### Spool Displacement and Valve Configuration

The *spool stroke* is the amount of spool travel an orifice takes to fully open from a closed position and is defined for each orifice selected on the **Valve Configuration** tab. The table below shows how the stroke is calculated in accordance with the valve orifice parameterization and flow path characteristics.

#### Spool Stroke Based on Parameterization and Flow Path

Orifice Parameterization	Identical for All Flow Paths	Different for Each Flow Path
Linear - Area vs. spool travel	Defined by the <b>Spool travel between closed and open orifice</b> parameter	Defined by the Spool travel between closed and open orifice parameter, for each orifice
Tabulated data - Area vs. spool travel	The difference between the first and last element of the <b>Spool travel vector</b> parameter	The difference between the first and last element of the spool travel vector parameter for each orifice
Tabulated data - Volumetric flow rate vs. spool travel and pressure drop	The difference between the first and last element of the <b>Spool travel vector, ds</b> parameter	The difference between the first and last element of the spool travel vector, ds parameter for each orifice

The section “Visualize Orifice Openings” on page 1-253 details how to see the orientation of all valve orifices.

The direction of spool movement signaled at port **S** depends on the spool stroke and the orifice orientation:

#### Orifice Definition and Spool Travel Direction

Spool Position when Orifice is Open	Spool Travel, $\Delta S$
Always closed (orifice is not selected in any spool position configuration)	N/A
Always open (orifice is selected in positive, neutral, and negative spool position configurations)	N/A
Negative	$S_{\text{orifice\_max}} + \text{spool stroke} - \mathbf{S}$
Negative and Neutral	$S_{\text{orifice\_max}} + \text{spool stroke} - \mathbf{S}$
Positive	$S_{\text{orifice\_max}} + \text{spool stroke} + \mathbf{S}$
Positive and Neutral	$S_{\text{orifice\_max}} + \text{spool stroke} + \mathbf{S}$
Neutral	$ S_{\text{orifice\_max}}  + \text{spool stroke} -  \mathbf{S} $
Positive and Negative	$- S_{\text{orifice\_max}}  + \text{spool stroke} -  \mathbf{S} $

Where  $S_{\text{orifice\_max}}$  is the spool position at the maximum orifice area defined for each orifice.

The **Consistency check for neutral spool position open connections** parameter verifies that

- Any orifice listed in **Neutral spool position open connections** is open when the signal at **S** is 0.
- Any orifice that is not listed in **Neutral spool position open connections** is closed when the signal at **S** is 0.

You can optionally choose to receive a warning or error when this check is violated.

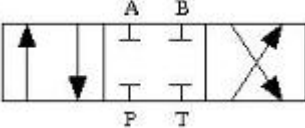
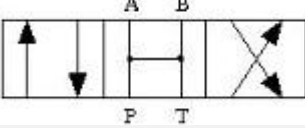
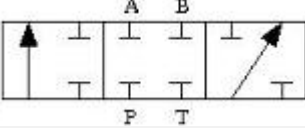
The possible configurations of the 4-Way 3-Position Directional Valve (IL) block are shown below.

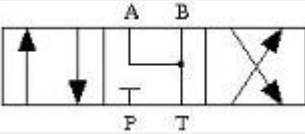
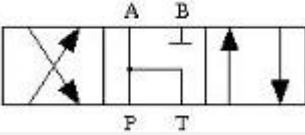
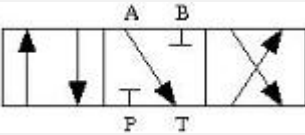
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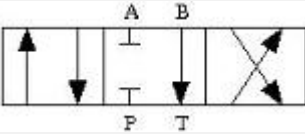
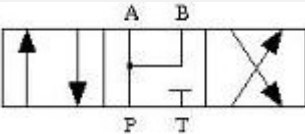
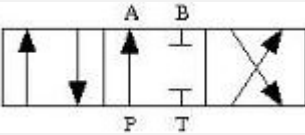
**Note** This block includes all configurations from the Hydraulic (Isothermal) library blocks 4-Way Directional Valve and the 4-Way Directional Valves A - K.

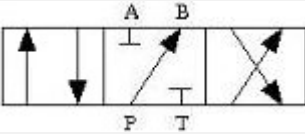
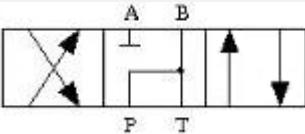
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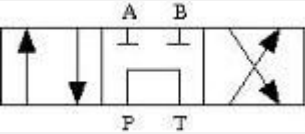
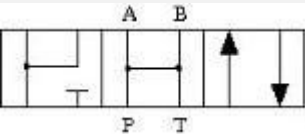
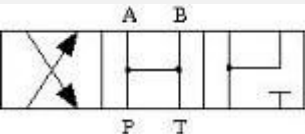
## 4-Way 3-Position Directional Valve Configuration

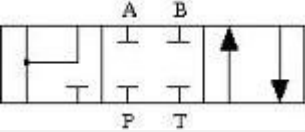
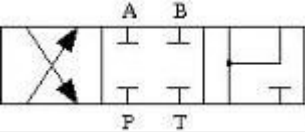
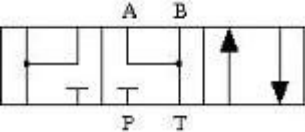
Configuration	Parameter Values
	<p>All four orifices are closed in the neutral position. (default)</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>All four orifices are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices A-T and B-T are closed. Orifices P-A and P-B are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A only</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-B only</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifices A-T and B-T are open. Orifices P-A and P-B are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices P-A and A-T are open in the neutral position. Orifices P-B and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-A and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> </ul>
	<p>Orifice A-T is open in the neutral position. Orifices P-B, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> A-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>

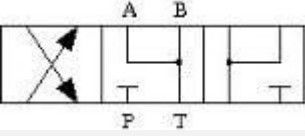
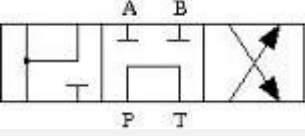
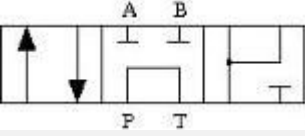
Configuration	Parameter Values
	<p>Orifice B-T is open in the neutral position. Orifices P-A, P-B, and A-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> B-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices P-A and P-B are open. Orifices A-T and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>Orifice P-A is open in the neutral position. Orifices P-B, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifice P-B is open in the neutral position. Orifices P-A, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-B only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>Orifices P-B and B-T are open in the neutral position. Orifices P-A and A-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-B and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifices P-A, P-B, A-T, and B-T are closed in the neutral position. P-T is open in the neutral position and closes when the spool displaces.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-A is a constant orifice. Orifices P-B, A-T, and B-T are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> = any value</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>
	<p>Orifice P-B is a constant orifice. Orifices P-A, A-T and B-T are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; -P-A spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>

Configuration	Parameter Values
	<p>Orifice P-A is closed in the neutral position. Ports <b>A</b> and <b>T</b> do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b> Spool position at maximum P-A orifice area  &gt; P-A spool stroke</b></li> <li>• <b>Spool position at maximum P-B orifice area &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum B-T orifice area &lt; -B-T spool stroke</b></li> </ul>
	<p>Orifice P-B is closed in the neutral position. Ports <b>B</b> and <b>T</b> do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area &lt; -P-A spool stroke</b></li> <li>• <b> Spool position at maximum P-B orifice area  &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum A-T orifice area &gt; A-T spool stroke</b></li> </ul>
	<p>Orifice P-A is closed in the neutral position. Orifice A-T is open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b> Spool position at maximum P-A orifice area  &gt; P-A spool stroke</b></li> <li>• <b>Spool position at maximum P-B orifice area &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum A-T orifice area = any value</b></li> <li>• <b>Spool position at maximum B-T orifice area &gt; -B-T spool stroke</b></li> </ul>



Configuration	Parameter Values
	<p>Orifice P-B is closed in the neutral position. Orifice B-T is open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b> Spool position at maximum P-B orifice area </b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-B is closed in the neutral position. Orifice P-T is open in the neutral position. Ports A and T do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b> Spool position at maximum P-B orifice area </b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-A is closed in the neutral position. Orifice P-T is open in the neutral position. Ports A and T do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b> Spool position at maximum P-A orifice area </b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>

## Valve Orifice Parameterizations

The **Orifice parameterization** parameter sets the model for the open area or volumetric flow rate through one or all of the valve orifices. The block applies the same data for all flow paths if **Area characteristics** is set to **Identical** for all flow paths; otherwise, individual parameterizations are applied for the **Different** for all flow paths setting. You can model valve opening in three ways:

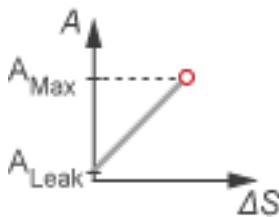
- Linear - area vs. spool travel

The opening area is a linear function of the spool position received as a signal at port **S**:

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where:

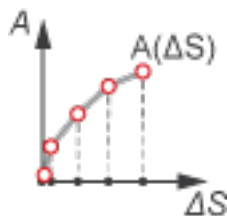
- $\Delta S$  is the spool travel defined in Orifice Definition and Spool Travel Direction.
- $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.
- $A_{max}$  is the **Maximum orifice area**.
- $A_{leak}$  is the **Leakage area**.



When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

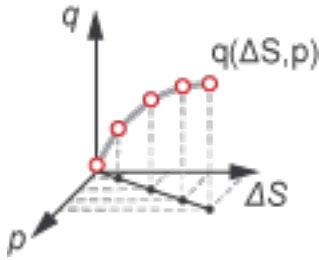
- Tabulated data - Area vs. spool travel

Provide spool travel vectors for your system or for individual flow paths between ports **P**, **A**, **B**, and **T**. This data will be used to calculate the relationship between the orifice area and spool displacement. Interpolation is used to determine the opening area between given data points.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the opening area vector, respectively.



- Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Provide spool travel and pressure drop vectors and a dependent, 2-D volumetric flow rate array. Interpolation is used to determine flow rate between given data points. The mass flow rate is the product of the volumetric flow rate and the local density.



### Visualize Orifice Openings

To visualize spool offsets and maximum displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the orifices selected in the **Valve Configuration** settings. The orifice parameterization sets the axes, which are either:

- Orifice area versus spool position
- Volumetric flow rate versus spool position, queried at a specific pressure differential

When the positive, neutral, and negative settings in the **Valve Configuration** feature the same orifice, the plot displays the orifice openings as a constant.

To update the data after changing the block parameters, click **Reload Data** on the figure window.

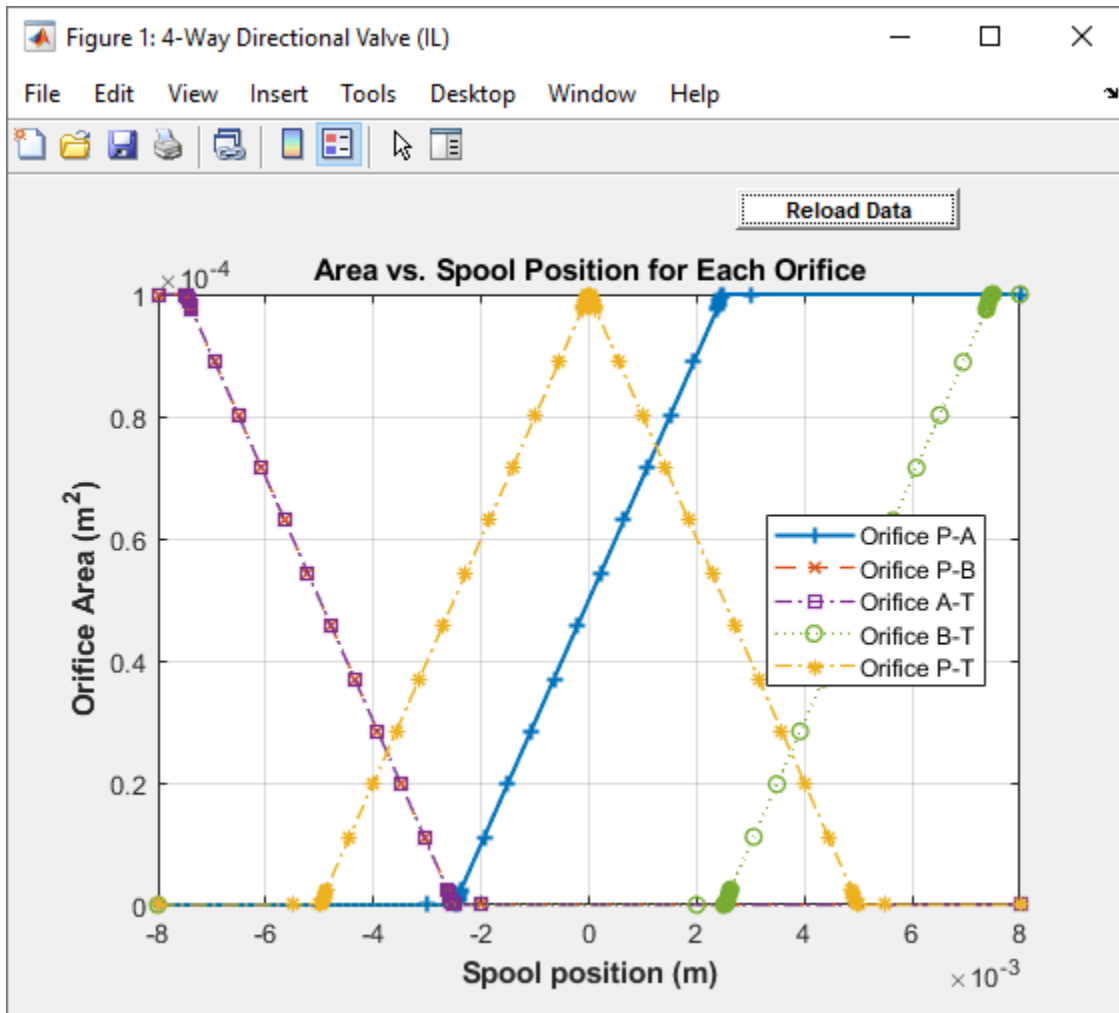
This image shows an example valve configuration. In the **Valve Configuration** settings:

- **Positive spool position open connections** is P-A and B-T.
- **Neutral spool position open connections** is P-T only.
- **Negative spool position open connections** is P-B and A-T.

In the **P-A Orifice** settings:

- **Spool position at maximum P-A orifice area** is  $2.5e-3$  m.

All other spool positions are at the default values.



### Example Spool Position Visualization

The visualization shows that the P-A orifice is open between the spool position at  $-2.53 \times 10^{-3}$  and  $2.53 \times 10^{-3}$  m. Because the P-A orifice is open only when the spool is displaced in the positive direction, setting the **Consistency check for neutral spool and position open connections** parameter to Warning returns:

Warning: P-A orifice must be closed when the spool is in the neutral position. Adjust Spool position at maximum P-A orifice area, Neutral spool position open connections, or Consistency check for neutral spool position open connections. Right-click on the block and select Fluids > Plot Valve Characteristics to view the area or flow of each connection versus spool position.

To resolve this warning, you can change:

- **Spool position at maximum P-A orifice area** to a value larger than 0.005 m.
- **Consistency check for neutral spool position open connections** to None.
- The valve configuration by setting **Neutral spool position open connections** to P-A only.

## Faults

When faults are enabled, the valve open area becomes stuck at a specified spool position in response to one of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **Tr**.

Four fault options are available in the **Spool position when faulted** parameter:

- **Positive** — The spool position freezes in the positive position, opening the **Positive spool position open connections** flow paths to their maximum value. The flow paths that are only open in the **Negative spool position open connections** and **Neutral spool position open connections** are closed.
- **Neutral** — The spool position freezes in the neutral position, opening all flow paths to their specified values at 0 m.
- **Negative** — The spool position freezes in the negative position, opening the **Negative spool position open connections** flow paths to their maximum value. The flow paths that are only open in the **Positive spool position open connections** and **Neutral spool position open connections** are closed.
- **Maintain last value** — The valve freezes at the spool position when the trigger occurs.

Due to numerical smoothing at the extremes of the valve area, in the linear parameterization, the minimum area applied is larger than the **Leakage area**, and the maximum is smaller than the **Maximum orifice area**, in proportion to the **Smoothing factor** value.

Once triggered, the valve remains at the faulted area for the rest of the simulation.

## Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see "List of Pre-Parameterized Components".

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

#### **B – Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

#### **P – Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

#### **T – Liquid port**

isothermal liquid

Liquid entry or exit port to the valve.

### Input

#### **S – Spool displacement, m**

physical signal

Spool displacement, in m, specified as a physical signal.

#### **Tr – External fault trigger**

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

### Dependencies

This port is visible when **Enable faults** is set to On and **Fault trigger** is set to External.

## Parameters

### Valve Configuration

#### **Positive spool position open connections – Flow paths open when the spool is in a positive position**

P-A and B-T (default) | P-A and P-B | P-B and A-T | P-A only | P-B only | P-A, P-B, and A-B

Flow paths open when the spool is in a positive position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. The settings for this parameter can be checked against the definitions for the other orifices for consistency when the **Consistency check for neutral spool position open connections** is set to Warning or Error.

**Neutral spool position open connections – Flow paths open when the spool is in the neutral position**

All closed (default) | P-A, P-B, A-T, and B-T | A-T and B-T | P-A and A-T | P-A and B-T | P-A and P-B | P-B and A-T | P-B and B-T | A-T only | B-T only | P-A only | P-B only | P-T only | P-A, A-T, and P-T | P-A, P-B, and A-B | P-B, B-T, and P-T | P-A, P-B, A-T, B-T, P-T

Flow paths open when the spool is in the neutral position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. The settings for this parameter can be checked against the definitions for the other orifices for consistency when the **Consistency check for neutral spool position open connections** is set to Warning or Error.

**Negative spool position open connections – Flow paths open when the spool moves in the negative direction**

P-A and B-T (default) | P-A and P-B | P-B and A-T | P-A only | P-B only | P-A, P-B, and A-B

Flow paths open when the spool moves in the negative direction. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. The settings for this parameter can be checked against the definitions for the other orifices for consistency when the **Consistency check for neutral spool position open connections** is set to Warning or Error.

**Consistency check for neutral spool position open connections – Whether to check if the orifice settings are consistent with the specified spool position for maximum orifice opening**

Warning (default) | Error | None

Whether to check if the neutral spool position open settings on the **Valve Configuration** tab are consistent with the specified spool position at the maximum orifice area. For each enabled orifice, the actual offset at the spool neutral position should be commensurate with the specified spool offset for each individual orifice.

**Model Parameterization****Area characteristics – Flow equations for orifices**

Identical for all flow paths (default) | Different for each flow path

Applies uniform or individual flow equations for the valve orifice area. **Identical for all flow paths** uses the same orifice and spool geometries, flow rates, pressure, and area vectors for all valve orifices. When using **Different for each flow path**, these parameters are specified individually for each orifice. In both cases, orifices **A**, **B**, **P**, and **T** have the same cross-sectional areas, discharge coefficients, and Reynolds numbers in the **Linear - Area vs. spool travel** and **Tabulated data - Area vs. spool travel** parameterizations. The same **Orifice parameterization** is applied to all flow paths.

**Orifice parameterization – Method of calculating opening area**

Linear area vs. spool travel (default) | Tabulated data - Area vs. spool travel | Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Method of calculating the valve opening area. In the tabulated data parameterizations, you can provide your own valve area and spool travel data for nonlinear valve opening profiles, or you can provide data in terms of volumetric flow rate, spool travel, and pressure drop over the flow path.

**Spool travel between closed and open orifice – Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Maximum orifice area – Maximum orifice opening area**1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of each orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Leakage area – Open area when an orifice is fully closed**1e-9 m<sup>2</sup> (default) | positive scalar

Open area when an orifice is fully closed. Any area smaller than this value is maintained at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - Area vs. spool travel.

**Spool travel vector – Vector of spool opening distances relative to fully closed position**[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**Orifice area vector – Vector of valve opening areas**[1e-09, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **Spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.



**Spool travel vector, ds — Vector of spool opening distances relative to fully closed position**[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Pressure drop vector, dp — Vector of valve pressure drop values**[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, ds** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Volumetric flow rate table, q(ds,dp) — Array of volumetric flow rates**[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; .00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **Spool travel vector, ds** parameter.
- *N* is the number of vector elements in the **Pressure drop vector, dp** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Constant orifice area — Orifice area for identical flow paths**1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to either:

- Linear - area vs. spool travel.
- Tabulated data - Area vs. spool travel

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

#### **Constant orifice pressure drop vector – Vector of pressure differential values for identical flow paths**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to `Tabulated data - Volumetric flow rate vs. spool travel and pressure drop`.

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

#### **Constant orifice volumetric flow rate vector – Vector of volumetric flow rate values for identical flow paths**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values for a constant orifice when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to `Tabulated data - Volumetric flow rate vs. spool travel and pressure drop`.

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

#### **Cross-sectional area at ports P, T, A and B – Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Maximum cross-sectional areas at the entry and exit ports **P**, **T**, **A**, and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

#### Dependencies

To enable this parameter, set **Area characteristics** to `Identical` for all flow paths and **Orifice parameterization** to either:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

#### Discharge coefficient – Discharge coefficient

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to either:

- Linear - Area vs. spool travel
- Tabulated data - Area vs. spool travel

#### Critical Reynolds number – Upper Reynolds number limit for laminar flow

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

#### Smoothing factor – Numerical smoothing factor

0.01 (default) | positive scalar in the range of [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

#### Dependencies

To enable this parameter, set **Orifice parametrization** to `Linear - area vs. spool travel`.

#### Pressure recovery – Whether to account for pressure increase in area expansions

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to:

- Linear - area vs. spool travel
- Tabulated data - Area vs. spool travel

### **P-A Orifice**

**Spool position at maximum P-A orifice area — Spool offset for fully open P-A orifice**  
7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open P-A orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

### **Dependencies**

To enable this parameter, set one of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

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**Note:** This parameter is enabled only when the P-A orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

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**P-A spool travel between closed and open orifice — Maximum spool stroke**  
0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A maximum orifice area — Maximum orifice opening area**

$1e-4 \text{ m}^2$  (default) | positive scalar

Largest open area of the P-A orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-A orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T

- P-A and B-T
- P-A and P-B
- P-A only

### **P-A orifice area vector — Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-A spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

#### **Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

#### **Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

#### **Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

### **P-A orifice spool travel vector, ds — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-A orifice pressure drop vector, dp** parameter for the 2-D dependent **P-A orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice pressure drop vector,  $dp$  – Vector of pressure drop values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-A orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-A orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**



- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A orifice volumetric flow rate table,  $q(ds, dp)$  – Array of volumetric flow rate values**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-A orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **P-A orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T

- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A constant orifice area — Cross-sectional area for a constant orifice**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B

- P-A only

**P-A Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-A Constant orifice volumetric flow rate vector — Vector of volumetric flow rates for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

**P-B Orifice****Spool position at maximum P-B orifice area — Spool offset from the neutral position for a fully open P-B orifice**

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open P-B orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

**Dependencies**

To enable this parameter, set one of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

---

**Note:** This parameter is enabled only when the P-B orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

**P-B spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

or set **Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

or set **Negative spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-B orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-B orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B orifice area vector — Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-B spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B orifice spool travel vector, ds — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector, dp** parameter for the 2-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only.

**Negative spool position open connections to:**



- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B orifice pressure drop vector,  $dp$  — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-B orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-B orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rate values**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;$   
 $-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;$   
 $-.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **P-B orifice spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **P-B orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B constant orifice area — Cross-sectional area for a constant orifice**

$1e-4$  m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3 One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T

- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

**P-B Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for a constant orifice**

`[-.0009, .0016, .002, .0024]` m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B

- P-B only

**Negative spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

### A-T Orifice

**Spool position at maximum A-T orifice area — Spool offset from the neutral position for a fully open A-T orifice**

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open A-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

### Dependencies

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-B and A-T.
- **Neutral spool position open connections** to:
  - P-A, P-B, A-T, and B-T
  - P-B and A-T
  - A-T and B-T
  - P-A and A-T
  - A-T only
- **Negative spool position open connections** to P-B and A-T.

---

**Note:** This parameter is enabled only when the A-T orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

**A-T spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.

2 **Orifice parameterization** to Linear - Area vs. spool travel.

3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the A-T orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

1 **Area characteristics** to Different for each flow path.

2 **Orifice parameterization** to Linear - Area vs. spool travel.

3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

#### **A-T orifice area vector – Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **A-T spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### **Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

#### **A-T orifice spool travel vector, ds – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **A-T orifice pressure drop vector, dp** parameter for the 2-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T orifice pressure drop vector,  $dp$  — Vector of pressure differential values**

[ -.1, .3, .5, .7 ] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-T orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **A-T orifice volumetric flow rate table,  $q(ds,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.



**A-T orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rate values**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;$   
 $-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;$   
 $-.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **A-T orifice spool travel vector, *ds*** parameter.
- *N* is the number of vector elements in the **A-T orifice pressure drop vector, *dp*** parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T constant orifice area — Cross-sectional area for a constant orifice**

$1e-4$  m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice pressure drop vector – Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **A-T Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice volumetric flow rate vector – Vector of volumetric flow rate values for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.

- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only

**Negative spool position open connections** to P-B and A-T.

### B-T Orifice

#### Spool position at maximum B-T orifice area — Spool offset from the neutral position for a fully open B-T orifice

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open B-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

#### Dependencies

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-A and B-T.
- **Neutral spool position open connections** to:
  - P-A, P-B, A-T, and B-T
  - A-T and B-T
  - P-A and B-T
  - P-B and B-T
  - B-T only
- **Negative spool position open connections** to P-A and B-T.

---

**Note:** This parameter is enabled only when the B-T orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

#### B-T spool travel between closed and open orifice — Maximum spool stroke

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to `Different` for each flow path.
- 2 Orifice parameterization** to `Linear - Area vs. spool travel`.
- 3** One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T maximum orifice area — Maximum orifice opening area**

$1e-4 \text{ m}^2$  (default) | positive scalar

Largest open area of the B-T orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to `Different` for each flow path.
- 2 Orifice parameterization** to `Linear - Area vs. spool travel`.
- 3** One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

$[0, .00125, .0025, .00375, .005]$  m (default) | 1-by- $n$  vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **B-T orifice area vector** parameter. The values

are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

### B-T orifice area vector — Vector of valve opening areas

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **B-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

### B-T orifice spool travel vector, ds — Vector of spool opening distances relative to fully closed position

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **B-T orifice pressure drop vector, dp** parameter for the 2-D dependent **B-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T orifice pressure drop vector, dp — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **B-T orifice spool travel vector, ds** parameter for the 2-D dependent **B-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T

- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T orifice volumetric flow rate table,  $q(ds, dp)$  — Array of volumetric flow rate values**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;$   
 $-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;$   
 $-.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **B-T orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **B-T orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T constant orifice area — Cross-sectional orifice area for constant orifices**

$1e-4$  m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to either:
  - Linear - area vs. spool travel
  - Tabulated data - Area vs. spool travel

- 3** One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice volumetric flow rate vector — Vector of volumetric flow rates for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.



**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only

**Negative spool position open connections** to P-A and B-T.

**P-T Orifice****Spool position at maximum P-T orifice area — Spool offset from the neutral position for a fully open P-T orifice**

0 m (default) | positive scalar

Spool offset from the neutral position for a fully open P-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions. To visualize the defined offsets, see “Visualize Orifice Openings” on page 1-253.

**Dependencies**

To enable this parameter, set **Neutral spool position open connections** to P-T only.

**P-T spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

**P-T maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-T orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

**P-T orifice spool travel vector – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

**P-T orifice spool travel vector, ds – Vector of spool opening distances relative to fully-closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector, dp** parameter for the 2-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

**P-T orifice pressure drop vector, dp – Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-T orifice spool travel vector, ds** parameter for the 2-D dependent **P-T orifice volumetric flow rate table, q(ds,dp)** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

#### **P-T orifice volumetric flow rate table, $q(ds, dp)$ — Array of volumetric flow rates**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;  
-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;  
-.00091, .0016, .002, .0024] m3/s (default) | M-by-N matrix`

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-T orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **P-T orifice pressure drop vector,  $dp$**  parameter.

#### **Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 **Neutral spool position open connections** to P-T only.

#### **Faults**

##### **Enable faults — Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Spool position area when faulted** parameter.

##### **Spool position when faulted — Set faulted characteristics**

Positive (default) | Neutral | Negative | Maintain last value

Sets the faulted valve spool position. You can choose for the valve to seize when the spool is in the positive position, negative position, or at the position when faulting is triggered.

#### **Dependencies**

To enable this parameter, set **Enable faults** to On.

##### **Fault trigger — External or temporal trigger option**

Temporal (default) | External

Whether a fault trigger occurs due to an external event or at a specified time.

When set to External, port **Tr** is enabled. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.

When set to Temporal, when the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Simulation time for fault event — Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Spool position when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

3-Way Directional Valve (IL) | Cartridge Valve Actuator (IL) | Shuttle Valve (IL) | 4-Way 3-Position Directional Valve (TL)

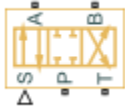
**Topics**

“Modeling Valves in Simscape Fluids”

## 4-Way 3-Position Directional Valve (TL)

Valve for routing flow at the junction of four lines in a thermal liquid network

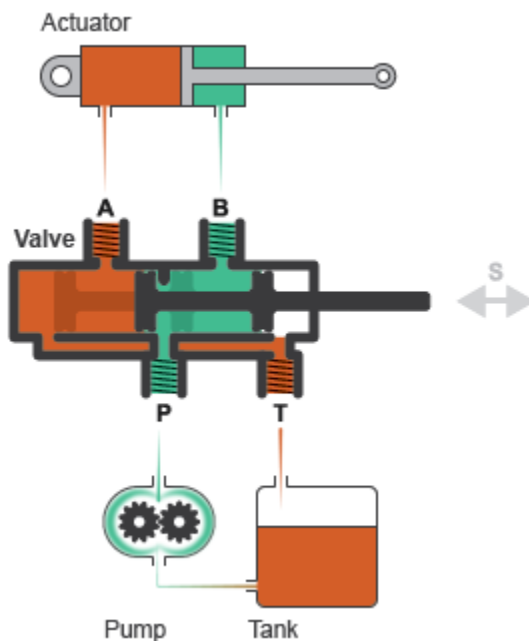
**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Directional Control Valves



### Description

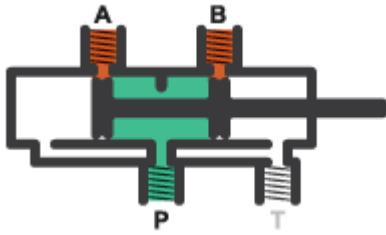
The 4-Way 3-Position Directional Valve (TL) block models a valve with four openings in a thermal liquid network, typically between an actuator, pump, and tank. The valve operation is controlled by a single spool displaced according to the signal at port **S**. You can set the baseline configuration of your valve by specifying the orifices that are open when the spool is in the neutral position (centered at 0 m) in the **Neutral spool position open connections** parameter, when the spool moves in the positive direction in the **Positive spool position open connections** parameter, and when the spool moves in the negative direction in the **Negative spool position open connections**.

You can set the model for valve opening in the **Orifice parameterization** parameter as a linear relationship or function of user-provided data, which can be applied to one or all flow paths in the valve.

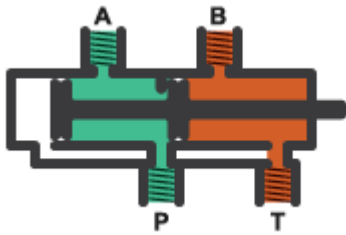


### Example Valve Setup

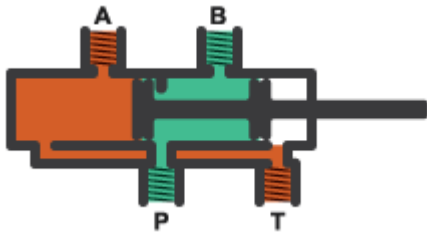
In this example configuration, **Neutral spool position open connections** is set to All closed. When the spool is in the neutral position, all orifices are closed to flow:



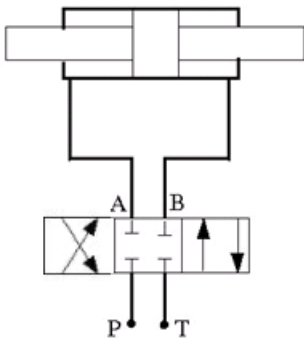
In this configuration, **Negative spool position open connections** is set to P-A and B-T. When the signal at port **S** moves the spool to a negative position, the paths between ports **P** and **A** and between ports **B** and **T** are open to flow. The paths between ports **P** and **B** and ports **A** and **T** are closed to flow:



In this configuration, **Positive spool position open connections** is set to P-B and A-T. When the signal at port **S** moves the spool to a positive position, the paths between ports **P** and **B** and between ports **A** and **T** are open to flow and the paths between ports **P** and **A** and between ports **B** and **T** are closed:



Schematically, this configuration is shown as:



The left-hand side corresponds to the positive position and the right-hand side corresponds to the negative position.

### Spool Displacement and Valve Configuration

The *spool stroke* is the amount of spool travel an orifice takes to fully open from a closed position and is defined for each orifice selected on the **Valve Configuration** tab. The table below shows how the stroke is calculated in accordance with the valve orifice parameterization and flow path characteristics.

The direction of spool movement signaled at port **S** depends on the spool stroke and the orifice orientation:

### Orifice Definition and Spool Travel Direction

Spool Position when Orifice is Open	Spool Travel, $\Delta S$
Always closed (orifice is not selected in any spool position configuration)	N/A
Always open (orifice is selected in positive, neutral, and negative spool position configurations)	N/A
Negative	$S_{\text{orifice\_max}} + \text{spool stroke} - \mathbf{S}$
Negative and Neutral	$S_{\text{orifice\_max}} + \text{spool stroke} - \mathbf{S}$
Positive	$S_{\text{orifice\_max}} + \text{spool stroke} + \mathbf{S}$
Positive and Neutral	$S_{\text{orifice\_max}} + \text{spool stroke} + \mathbf{S}$
Neutral	$ S_{\text{orifice\_max}}  + \text{spool stroke} -  \mathbf{S} $
Positive and Negative	$- S_{\text{orifice\_max}}  + \text{spool stroke} -  \mathbf{S} $

Where  $S_{\text{orifice\_max}}$  is the spool position at the maximum orifice area defined for each orifice.

The **Consistency check for neutral spool position open connections** parameter verifies that

- Any orifice listed in **Neutral spool position open connections** is open when the signal at **S** is 0.
- Any orifice that is not listed in **Neutral spool position open connections** is closed when the signal at **S** is 0.

You can optionally choose to receive a warning or error when this check is violated.

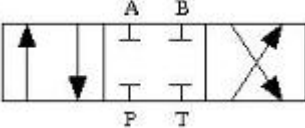
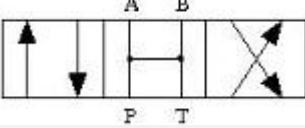
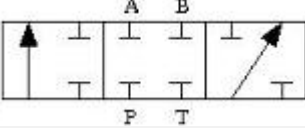
The possible configurations of the 4-Way 3-Position Directional Valve (TL) block are shown below.

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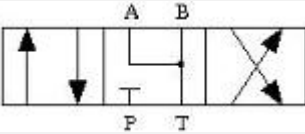
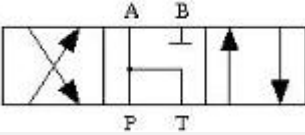
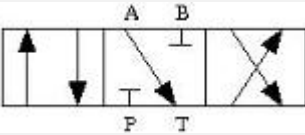
**Note** This block includes all configurations from the Hydraulic (Isothermal) library blocks 4-Way Directional Valve and the 4-Way Directional Valves A - K.

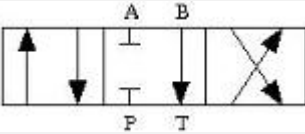
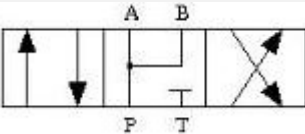
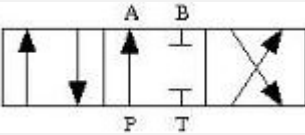
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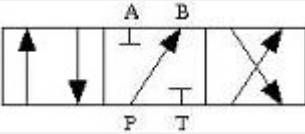
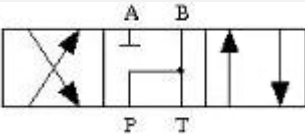
### 4-Way 3-Position Directional Valve Configuration

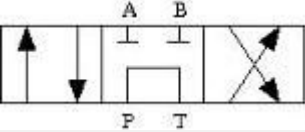
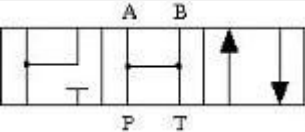
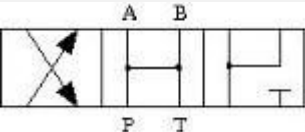
Configuration	Parameter Values
	<p>All four orifices are closed in the neutral position. (default)</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>All four orifices are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices A-T and B-T are closed. Orifices P-A and P-B are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A only</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-B only</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> </ul>

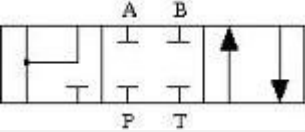
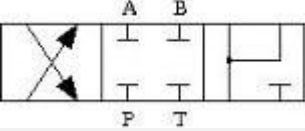
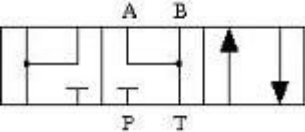


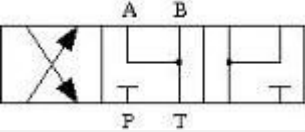
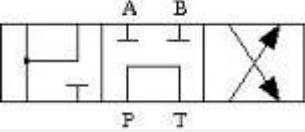
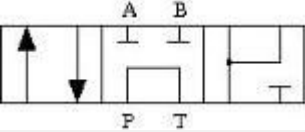
Configuration	Parameter Values
	<p>Orifices A-T and B-T are open. Orifices P-A and P-B are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices P-A and A-T are open in the neutral position. Orifices P-B and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-A and A-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> </ul>
	<p>Orifice A-T is open in the neutral position. Orifices P-B, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> A-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifice B-T is open in the neutral position. Orifices P-A, P-B, and A-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> B-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; B-T spool stroke</li> </ul>
	<p>Orifices P-A and P-B are open. Orifices A-T and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A and P-B</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>Orifice P-A is open in the neutral position. Orifices P-B, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-A only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifice P-B is open in the neutral position. Orifices P-A, A-T, and B-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-B only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &gt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> </ul>
	<p>Orifices P-B and B-T are open in the neutral position. Orifices P-A and A-T are overlapped.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-B and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &gt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>

Configuration	Parameter Values
	<p>Orifices P-A, P-B, A-T, and B-T are closed in the neutral position. P-T is open in the neutral position and closes when the spool displaces.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; -A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-A is a constant orifice. Orifices P-B, A-T, and B-T are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> = any value</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; -B-T spool stroke</li> </ul>
	<p>Orifice P-B is a constant orifice. Orifices P-A, A-T and B-T are open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> P-A, P-B, A-T, and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; -P-A spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>

Configuration	Parameter Values
	<p>Orifice P-A is closed in the neutral position. Ports <b>A</b> and <b>T</b> do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b> Spool position at maximum P-A orifice area  &gt; P-A spool stroke</b></li> <li>• <b>Spool position at maximum P-B orifice area &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum B-T orifice area &lt; -B-T spool stroke</b></li> </ul>
	<p>Orifice P-B is closed in the neutral position. Ports <b>B</b> and <b>T</b> do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> All closed</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area &lt; -P-A spool stroke</b></li> <li>• <b> Spool position at maximum P-B orifice area  &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum A-T orifice area &gt; A-T spool stroke</b></li> </ul>
	<p>Orifice P-A is closed in the neutral position. Orifice A-T is open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and B-T</li> <li>• <b> Spool position at maximum P-A orifice area  &gt; P-A spool stroke</b></li> <li>• <b>Spool position at maximum P-B orifice area &gt; P-B spool stroke</b></li> <li>• <b>Spool position at maximum A-T orifice area = any value</b></li> <li>• <b>Spool position at maximum B-T orifice area &gt; -B-T spool stroke</b></li> </ul>

Configuration	Parameter Values
	<p>Orifice P-B is closed in the neutral position. Orifice B-T is open in the neutral position.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-B and A-T</li> <li>• <b>Neutral spool position open connections:</b> A-T and B-T</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b>Spool position at maximum P-A orifice area</b> &lt; -P-A spool stroke</li> <li>• <b> Spool position at maximum P-B orifice area </b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum A-T orifice area</b> &lt; A-T spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-B is closed in the neutral position. Orifice P-T is open in the neutral position. Ports A and T do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and P-B</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-B and A-T</li> <li>• <b>Spool position at maximum P-A orifice area</b> &gt; P-A spool stroke</li> <li>• <b> Spool position at maximum P-B orifice area </b> &gt; P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &lt; -B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>
	<p>Orifice P-A is closed in the neutral position. Orifice P-T is open in the neutral position. Ports A and T do not form a flow path.</p> <ul style="list-style-type: none"> <li>• <b>Positive spool position open connections:</b> P-A and B-T</li> <li>• <b>Neutral spool position open connections:</b> P-T only</li> <li>• <b>Negative spool position open connections:</b> P-A and P-B</li> <li>• <b> Spool position at maximum P-A orifice area </b> &gt; P-A spool stroke</li> <li>• <b>Spool position at maximum P-B orifice area</b> &lt; -P-B spool stroke</li> <li>• <b>Spool position at maximum B-T orifice area</b> &gt; B-T spool stroke</li> <li>• <b>Spool position at maximum P-T orifice area</b> = any value</li> </ul>

## Valve Orifice Parameterizations

The **Orifice parameterization** parameter sets the model for the open area or volumetric flow rate through one or all of the valve orifices. The block applies the same data for all flow paths if **Area characteristics** is set to **Identical** for all flow paths; otherwise, individual parameterizations are applied for the **Different** for all flow paths setting. You can model valve opening in three ways:

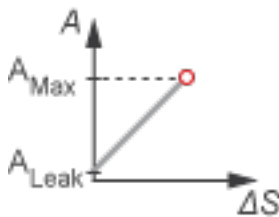
- Linear - Area vs. spool travel

The opening area is a linear function of the spool position received as a signal at port **S**:

$$A_{orifice} = \frac{(A_{max} - A_{leak})}{\Delta S_{max}} \Delta S + A_{leak},$$

where:

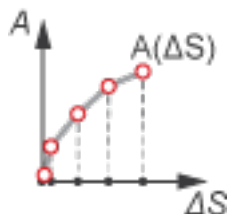
- $\Delta S$  is the spool travel defined in “Spool Displacement and Valve Configuration” on page 1-297.
- $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.
- $A_{max}$  is the **Maximum orifice area**.
- $A_{leak}$  is the **Leakage area**.



When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{leak}$  and  $A_{max}$ . For more information, see “Numerical Smoothing”.

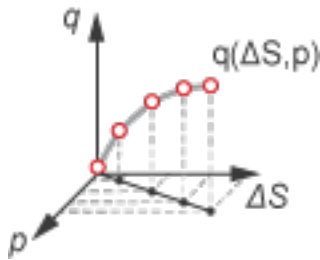
- Tabulated data - Area vs. spool travel

Provide spool travel vectors for your system or for individual flow paths between ports **P**, **A**, **B**, and **T**. This data will be used to calculate the relationship between the orifice area and spool displacement. Interpolation is used to determine the opening area between given data points.  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the opening area vector, respectively.



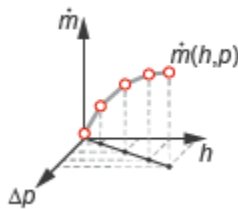
- Tabulated data - Volumetric flow rate vs. spool travel and pressure drop

Provide spool travel and pressure drop vectors and a dependent, 2-D volumetric flow rate array. Interpolation is used to determine flow rate between given data points. The mass flow rate is the product of the volumetric flow rate and the local density.



- Tabulated data - Mass flow rate vs. spool travel and pressure drop

Calculate the mass flow rate directly from the control member position and the pressure drop across the valve. The relationship between the three variables can be nonlinear, the block calculates it from the tabulated data in the **Spool travel vector,  $\mathbf{ds}$** , **Pressure drop vector,  $\mathbf{dp}$** , and **Mass flow rate table,  $\mathbf{mdot}(\mathbf{ds}, \mathbf{dp})$**  parameters.



### Visualize Orifice Openings

To visualize spool offsets and maximum displacement, right-click the block and select **Fluids > Plot Valve Characteristics**. The plot shows the orifices selected in the **Valve Configuration** settings. The orifice parameterization sets the axes, which are either:

- Orifice area versus spool position
- Volumetric flow rate versus spool position, queried at a specific pressure differential
- Mass flow rate versus spool position for the reference inflow temperature and reference inflow pressure, queried at a specific pressure differential

When the positive, neutral, and negative settings in the **Valve Configuration** feature the same orifice, the plot displays the orifice openings as a constant.

To update the data after changing the block parameters, click **Reload Data** on the figure window.

This image shows an example valve configuration. In the **Valve Configuration** settings:

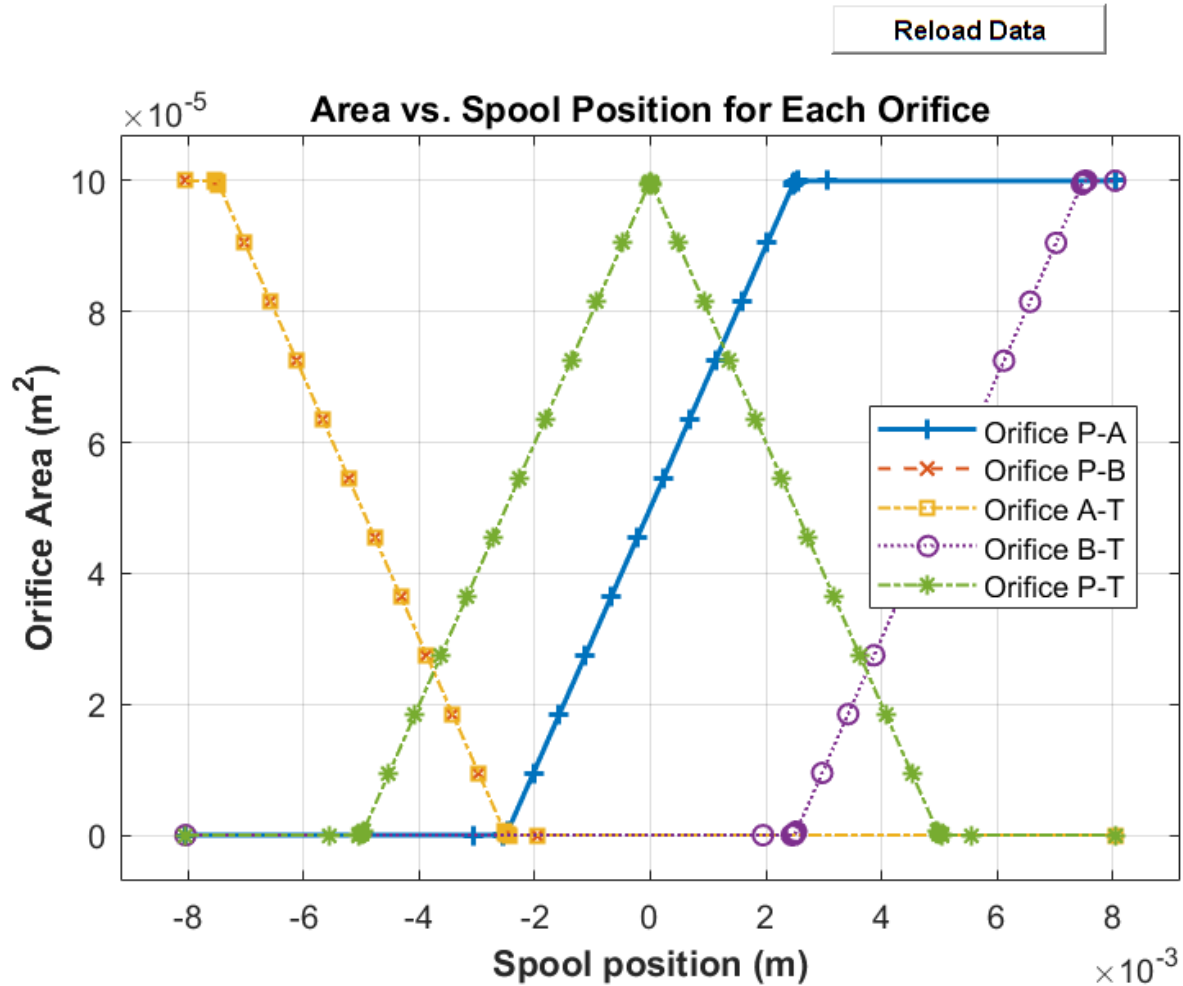
- **Positive spool position open connections** is P-A and B-T.
- **Neutral spool position open connections** is P-T only.
- **Negative spool position open connections** is P-B and A-T.

In the **P-A Orifice** settings:

- **Spool position at maximum P-A orifice area** is  $2.5e-3$  m.

All other spool positions are at the default values.





The visualization shows that the P-A orifice is open between the spool position at  $-2.53 \times 10^{-3}$  and  $2.53 \times 10^{-3}$  m. Because the P-A orifice is open only when the spool is displaced in the positive direction, setting the **Consistency check for neutral spool and position open connections** parameter to Warning returns:

Warning: P-A orifice must be closed when the spool is in the neutral position. Adjust Spool position at maximum P-A orifice area, Neutral spool position open connections, or Consistency check for neutral spool position open connections. Right-click on the block and select Fluids > Plot Valve Characteristics to view the area or flow of each connection versus spool position.

To resolve this warning, you can change:

- **Spool position at maximum P-A orifice area** to a value larger than 0.005 m.
- **Consistency check for neutral spool position open connections** to None.
- The valve configuration by setting **Neutral spool position open connections** to P-A only.

## Leakage Flow

The primary purpose of the leakage flow rate of a closed valve is to ensure that at no time a portion of the thermal liquid network becomes isolated from the remainder of the model. Such isolated portions reduce the numerical robustness of the model and can slow down simulation or cause it to fail. Leakage flow is generally present in real valves but in a model its exact value is less important than its being a small number greater than zero. The leakage flow rate is determined from the **Leakage area** block parameter.

## Ports

### Input

#### **S — Spool or valve control member, unitless**

physical signal

Instantaneous displacement of the valve control member.

### Conserving

#### **P — Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to a fluid supply line.

#### **T — Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to a fluid return line.

#### **A — Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to an actuation line.

#### **B — Flow passage**

thermal liquid

Opening through which the flow can enter or exit the valve. This port is typically connected to an actuation line.

## Parameters

### Valve Configuration

#### **Positive spool position open connections — Flow paths open when the spool is in a positive position**

P-A and B-T (default) | P-A and P-B | P-B and A-T | P-A only | P-B only | P-A, P-B, and A-B

Flow paths open when the spool is in a positive position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. To check the

parameter settings for consistency with other orifices, set **Consistency check for neutral spool position open connections** to Warning or Error.

#### **Neutral spool position open connections – Flow paths open when the spool is in the neutral position**

All closed (default) | P-A, P-B, A-T, and B-T | A-T and B-T | P-A and A-T | P-A and B-T | P-A and P-B | P-B and A-T | P-B and B-T | A-T only | B-T only | P-A only | P-B only | P-T only | P-A, A-T, and P-T | P-A, P-B, and A-B | P-B, B-T, and P-T | P-A, P-B, A-T, B-T, P-T

Flow paths open when the spool is in the neutral position. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. To check the parameter settings for consistency with other orifices, set **Consistency check for neutral spool position open connections** to Warning or Error.

#### **Negative spool position open connections – Flow paths open when the spool moves in the negative direction**

P-A and B-T (default) | P-A and P-B | P-B and A-T | P-A only | P-B only | P-A, P-B, and A-B

Flow paths open when the spool moves in the negative direction. This parameter sets the valve configuration and defines the direction of spool movement according to the signal received at port **S**. To check the parameter settings for consistency with other orifices, set **Consistency check for neutral spool position open connections** to Warning or Error.

#### **Consistency check for neutral spool position open connections – Whether to check if the orifice settings are consistent with the specified spool position for maximum orifice opening**

Warning (default) | Error | None

Whether to check if the neutral spool position open settings on the **Valve Configuration** tab are consistent with the specified spool position at the maximum orifice area. For each enabled orifice, the actual offset at the spool neutral position should be commensurate with the specified spool offset for each individual orifice.

### **Model Parameterization**

#### **Area characteristics – Flow equations for orifices**

Identical for all flow paths (default) | Different for each flow path

Applies uniform or individual flow equations for the valve orifice area. Identical for all flow paths uses the same orifice and spool geometries, flow rates, pressure, and area vectors for all valve orifices. When using Different for each flow path, these parameters are specified individually for each orifice. In both cases, all orifices have the same cross-sectional areas, discharge coefficients, and Reynolds numbers in the Linear - Area vs. spool travel and Tabulated data - Area vs. spool travel parameterizations. The same **Orifice parameterization** is applied to all flow paths.

#### **Orifice parameterization – Method of calculating opening area**

Linear - Area vs. spool travel (default) | Tabulated data - Area vs. spool travel | Tabulated data - Volumetric flow rate vs. spool travel and pressure drop | Tabulated data - Mass flow rate vs. spool travel and pressure drop

Method of calculating the valve opening area. In the tabulated data parameterizations, you can provide your own valve area and spool travel data for nonlinear valve opening profiles, or you can provide data in terms of volumetric flow rate, spool travel, and pressure drop over the flow path.

**Spool travel between closed and open orifice – Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Maximum orifice area – Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of each orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Linear - Area vs. spool travel.

**Leakage area – Open area when an orifice is fully closed**

1e-9 m<sup>2</sup> (default) | positive scalar

Open area when an orifice is fully closed. Any area smaller than this value is maintained at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - Area vs. spool travel.

**Spool travel vector – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**Orifice area vector – Vector of valve opening areas**

[1e-09, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **Spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Area vs. spool travel.

**Spool travel vector, ds – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parametrization of volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, dp** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Pressure drop vector, dp – Vector of valve pressure drop values**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Spool travel vector, ds** parameter for the 2-D dependent **Volumetric flow rate table, q(ds,dp)** or **Mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Volumetric flow rate table, q(ds,dp) – Array of volumetric flow rates**

[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; .00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **Spool travel vector, ds** parameter.
- *N* is the number of vector elements in the **Pressure drop vector, dp** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

**Mass flow rate table, mdot(ds,dp) – Mass flow rate**

[-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) | *M*-by-*N* matrix

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.

#### **Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

#### **Constant orifice area – Orifice area for identical flow paths**

$1e-4 \text{ m}^2$  (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions feature the same orifice.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to either:

- Linear - Area vs. spool travel.
- Tabulated data - Area vs. spool travel

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

#### **Constant orifice pressure drop vector – Vector of pressure differential values for identical flow paths**

$[-.1, .3, .5, .7]$  MPa (default) | 1-by- $n$  vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions feature the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** or **Constant orifice mass flow rate table,  $mdot(ds,dp)$**  parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

**Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for identical flow paths**[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values for a constant orifice when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

**Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**[-.9, 1.6, 2, 2.4] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for all flow paths and **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

The same orifice must be selected in all three of the **Valve Configuration** parameters:

- **Positive spool position open connections**
- **Neutral spool position open connections**
- **Negative spool position open connections**

**Reference inflow temperature — Temperature at which mass flow rate data is specified**

293.15 K (default) | positive scalar

Temperature at which the tabulated mass flow rate data is specified.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Reference inflow pressure — Pressure at which mass flow rate tabulated data is specified**

0.101325 MPa (default) | positive scalar

Pressure at which the tabulated mass flow rate data is specified. The block uses this parameter to calculate a third reference parameter, the reference density. The reference that it uses to scale the tabulated pressure drop data for pressures and temperatures deviating from the reference conditions.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.

**Cross-sectional area at ports P, T, A and B — Area at conserving ports**

0.01 m<sup>2</sup> (default) | positive scalar

Maximum cross-sectional areas at the entry and exit ports **P**, **T**, **A**, and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve and energy flow rate smoothing.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to either:

- Linear - Area vs. spool travel
- Tabulated data - Area vs. spool travel

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to:

- Linear - Area vs. spool travel
- Tabulated data - Area vs. spool travel

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range of [0,1]

Continuous smoothing factor that introduces a layer of gradual change based to the flow response when the valve is in near-open and near-closed positions. To increase the stability of your simulation in these regimes, set this parameter to a nonzero value less than one.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Linear - Area vs. spool travel.

**Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.



**Dependencies**

To enable this parameter, set **Orifice parameterization** to:

- Linear - Area vs. spool travel
- Tabulated data - Area vs. spool travel

**P-A Orifice**

**Spool position at maximum P-A orifice area — Spool offset for fully open P-A orifice**  
 $7.5e-3$  m (default) | positive scalar

Spool offset from the neutral position for a fully open P-A orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

**Dependencies**

To enable this parameter, set one of the following parameters:

**Positive spool position open connections** to:

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

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**Note:** This parameter is enabled only when the P-A orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

**P-A spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-A orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A orifice area vector — Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-A spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A orifice spool travel vector,  $ds$  — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by- $n$  vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-A orifice pressure drop vector,  $dp$**  parameter for the 2-D dependent **P-A orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-A orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T

- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A orifice pressure drop vector,  $dp$  — Vector of pressure drop values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for the tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-A orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-A orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-A orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A orifice volumetric flow rate table,  $q(ds, dp)$  — Array of volumetric flow rate values**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;  
-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;  
-.00091, .0016, .002, .0024] m3/s (default) | M-by-N matrix`

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-A orifice spool travel vector, *ds*** parameter.
- *N* is the number of vector elements in the **P-A orifice pressure drop vector, *dp*** parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A orifice mass flow rate table,  $\dot{m}(ds,dp)$  — Array of mass flow rate values**

[-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mass flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-A orifice spool travel vector, *ds*** parameter.
- *N* is the number of vector elements in the **P-A orifice pressure drop vector, *dp*** parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A constant orifice area — Cross-sectional area for a constant orifice**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions use the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - Area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B



- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[ -.1, .3, .5, .7 ] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice volumetric flow rate vector** or **P-A Constant orifice mass flow rate table**, **mdot(ds,dp)** parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only

- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A Constant orifice volumetric flow rate vector — Vector of volumetric flow rates for a constant orifice**

`[-.0009, .0016, .002, .0024]` m<sup>3</sup>/s (default) | 1-by-n vector

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-A Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**

[ -0.9, 1.6, 2, 2.4 ] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-A Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T
- P-A and B-T
- P-A and P-B
- P-A only
- P-A, A-T, and P-T
- P-A, P-B, and A-B
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-A and A-T

- P-A and B-T
- P-A and P-B
- P-A only
- P-A, P-B, and A-B

**P-B Orifice****Spool position at maximum P-B orifice area — Spool offset from the neutral position for a fully open P-B orifice**

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open P-B orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

**Dependencies**

To enable this parameter, set one of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

---

**Note:** This parameter is enabled only when the P-B orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

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**P-B spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B maximum orifice area — Maximum orifice opening area**1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-B orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-B orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice area vector – Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **P-B spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice spool travel vector,  $ds$  — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by- $n$  vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **P-B orifice pressure drop vector,  $dp$**  parameter for the 2-D dependent **P-B orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-B orifice mass flow rate table,  $m\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T



- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice pressure drop vector,  $dp$  — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-n vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-B orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-B orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-B orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T

- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice volumetric flow rate table,  $q(ds, dp)$  — Array of volumetric flow rate values**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024;  
-.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014;  
-.00091, .0016, .002, .0024] m^3/s (default) | M-by-N matrix`

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-B orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **P-B orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T

- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B orifice mass flow rate table,  $\dot{m}(ds, dp)$  — Array of mass flow rate values**  
 [-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mass flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-B orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **P-B orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only

- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B constant orifice area — Cross-sectional area for a constant orifice**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions use the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - Area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice volumetric flow rate vector** or **P-B Constant orifice mass flow rate table**, **mdot(ds,dp)** parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T

- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**P-B Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-n vector

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B

- P-B only
- P-A, P-B, and A-B

**P-B Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**

[-.9, 1.6, 2, 2.4] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3** One of the following settings in each parameter:

**Positive spool position open connections to:**

- P-B and A-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections to:**

- P-A, P-B, A-T, and B-T
- P-B and A-T
- P-B and B-T
- P-A and P-B
- P-B only
- P-A, P-B, and A-B

## A-B Orifice

### Spool position at maximum A-B orifice area — Spool offset from the neutral position for a fully open A-B orifice

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open A-B orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

#### Dependencies

To enable this parameter, set one of the following parameters:

#### Positive spool position open connections to:

- P-A, P-B, and A-B

#### Neutral spool position open connections to:

- P-A, P-B, and A-B

#### Negative spool position open connections to:

- P-A, P-B, and A-B

---

**Note:** This parameter is enabled only when the P-A orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

### A-B spool travel between closed and open orifice — Maximum spool stroke

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

#### Positive spool position open connections to:

- P-A, P-B, and A-B

#### Neutral spool position open connections to:

- P-A, P-B, and A-B

#### Negative spool position open connections to:

- P-A, P-B, and A-B



**A-B maximum orifice area — Maximum orifice opening area**1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the A-B orifice during the operation of the valve.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-B orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B orifice area vector — Vector of valve opening areas**[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **A-B spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B orifice spool travel vector, ds — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **A-B orifice pressure drop vector, dp** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B orifice pressure drop vector, dp — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-B orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **A-B orifice volumetric flow rate table,  $q(ds,dp)$**  or **A-B orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to:

- P-A, P-B, and A-B

**Neutral spool position open connections** to:

- P-A, P-B, and A-B

**Negative spool position open connections** to:

- P-A, P-B, and A-B

**A-B orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rate values**

`[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m^3/s (default) | M-by-N matrix`

M-by-N matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **A-B orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **A-B orifice pressure drop vector,  $dp$**  parameter.

### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to:

- P-A, P-B, and A-B

**Neutral spool position open connections** to:

- P-A, P-B, and A-B

**Negative spool position open connections** to:

- P-A, P-B, and A-B

**A-B orifice mass flow rate table,  $\dot{m}(ds, dp)$  — Array of mass flow rate values**  
[-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mass flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **A-B orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **A-B orifice pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to:

- P-A, P-B, and A-B

**Neutral spool position open connections** to:

- P-A, P-B, and A-B

**Negative spool position open connections** to:

- P-A, P-B, and A-B

**A-B constant orifice area — Cross-sectional area for a constant orifice**  
1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions use the same orifice.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to:

- P-A, P-B, and A-B

**Neutral spool position open connections** to:

- P-A, P-B, and A-B

**Negative spool position open connections** to:

- P-A, P-B, and A-B

**A-B Constant orifice pressure drop vector — Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **A-B Constant orifice volumetric flow rate vector** or **A-B Constant orifice mass flow rate table,  $\mathbf{m\dot{d}ot(ds,dp)}$**  parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B Constant orifice volumetric flow rate vector — Vector of volumetric flow rate values for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **A-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-B Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**

[ -0.9, 1.6, 2, 2.4 ] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **A-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections to:**

- P-A, P-B, and A-B

**Neutral spool position open connections to:**

- P-A, P-B, and A-B

**Negative spool position open connections to:**

- P-A, P-B, and A-B

**A-T Orifice**

**Spool position at maximum A-T orifice area — Spool offset from the neutral position for a fully open A-T orifice**

7.5e-3 m (default) | positive scalar

Spool offset from the neutral position for a fully open A-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

**Dependencies**

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-B and A-T.
- **Neutral spool position open connections to:**
  - P-A, P-B, A-T, and B-T
  - P-B and A-T
  - A-T and B-T

- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T
- **Negative spool position open connections** to P-B and A-T.

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**Note:** This parameter is enabled only when the A-T orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

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### A-T spool travel between closed and open orifice — Maximum spool stroke

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

### A-T maximum orifice area — Maximum orifice opening area

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the A-T orifice during the operation of the valve.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.

- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **A-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set:

- 1** **Area characteristics** to Different for each flow path.
- 2** **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T orifice area vector — Vector of valve opening areas**

[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector



Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **A-T spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T orifice spool travel vector, ds** — Vector of spool opening distances relative to fully closed position

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **A-T orifice pressure drop vector, dp** parameter for the 2-D dependent **A-T orifice volumetric flow rate table, q(ds,dp)** or **A-T orifice mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T

- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

### **A-T orifice pressure drop vector, $dp$ — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **A-T orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **A-T orifice volumetric flow rate table,  $q(ds,dp)$**  or **A-T orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

### **A-T orifice volumetric flow rate table, $q(ds,dp)$ — Array of volumetric flow rate values**

[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **A-T orifice spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **A-T orifice pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T orifice mass flow rate table,  $mdot(ds,dp)$  — Array of mass flow rate values**  
 [-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **A-T orifice spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **A-T orifice pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T

- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T constant orifice area – Cross-sectional area for a constant orifice**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions use the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - Area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice pressure drop vector – Vector or pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **A-T Constant orifice volumetric flow rate vector** or **A-T Constant orifice mass flow rate table,  $\dot{m}(\mathbf{ds}, \mathbf{dp})$**  parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice volumetric flow rate vector – Vector of volumetric flow rate values for a constant orifice**

[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | 1-by-n vector

Vector of volumetric flow rate values when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **Constant orifice volumetric flow rate vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**A-T Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**

[-.9, 1.6, 2, 2.4] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following settings in each parameter:

**Positive spool position open connections** to P-B and A-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- P-B and A-T
- A-T and B-T
- P-A and A-T
- A-T only
- P-A, A-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-B and A-T.

**B-T Orifice**

**Spool position at maximum B-T orifice area — Spool offset from the neutral position for a fully open B-T orifice**

$7.5e-3$  m (default) | positive scalar

Spool offset from the neutral position for a fully open B-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

**Dependencies**

To enable this parameter, set one of the following parameters:

- **Positive spool position open connections** to P-A and B-T.
- **Neutral spool position open connections** to:
  - P-A, P-B, A-T, and B-T

- A-T and B-T
  - P-A and B-T
  - P-B and B-T
  - B-T only
  - P-B, B-T, and P-T
  - P-A, P-B, A-T, B-T, P-T
- **Negative spool position open connections** to P-A and B-T.

---

**Note:** This parameter is enabled only when the B-T orifice settings do not appear in all three spool position parameters: **Positive spool position open connections**, **Neutral spool position open connections**, and **Negative spool position open connections**.

---

### **B-T spool travel between closed and open orifice – Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### **Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Linear - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

### **B-T maximum orifice area – Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the B-T orifice during the operation of the valve.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T orifice spool travel vector – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of spool travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **B-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3** One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.



**B-T orifice area vector – Vector of valve opening areas**[1e-10, 1e-05, 4e-05, 6e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of opening areas for the tabular parameterization of valve opening area. The vector elements must correspond one-to-one with the elements in the **B-T orifice spool travel vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T orifice spool travel vector, ds – Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-n vector

Vector of control member travel distances for the tabular parameterization of volumetric flow rates. The spool travel vector forms an independent axis with the **B-T orifice pressure drop vector, dp** parameter for the 2-D dependent **B-T orifice volumetric flow rate table, q(ds,dp)** or **B-T orifice mass flow rate table, mdot(ds,dp)** parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

### **B-T orifice pressure drop vector, $dp$ — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **B-T orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **B-T orifice volumetric flow rate table,  $q(ds,dp)$**  or **B-T orifice mass flow rate table,  $mdot(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

### **B-T orifice volumetric flow rate table, $q(ds,dp)$ — Array of volumetric flow rate values**

[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -.00036, .00063, .00081, .00096; -.00054, .00094, .0012, .0014; -.00091, .0016, .002, .0024] m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **B-T orifice spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **B-T orifice pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T orifice mass flow rate table,  $mdot(ds,dp)$  — Array of mass flow rate values**  
 [-1e-05, 1.7e-05, 2e-05, 2.6e-05; -.009, .0035, .0045, .0053; -.36, .7, .9, 1.06; -.54, 1.96, 2.5, 3; -.91, 6, 7.7, 9.13] kg/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mass flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **B-T orifice spool travel vector,  $ds$**  parameter.
- $N$  is the number of vector elements in the **B-T orifice pressure drop vector,  $dp$**  parameter.

#### Dependencies

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the following parameters:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T

- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T constant orifice area – Cross-sectional orifice area for constant orifices**

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice area when the positive, neutral, and negative spool positions use the same orifice.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to either:
  - Linear - Area vs. spool travel
  - Tabulated data - Area vs. spool travel
- 3** One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice pressure drop vector – Vector of pressure differential values for a constant orifice**

[-.1, .3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure differential values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice volumetric flow rate vector** or **B-T Constant orifice mass flow rate table,  $\dot{m}(\mathbf{ds}, \mathbf{dp})$**  parameters. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop or Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice volumetric flow rate vector – Vector of volumetric flow rates for a constant orifice**

`[-.0009, .0016, .002, .0024] m3/s (default) | 1-by-n vector`

Vector of volumetric flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **B-T Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**B-T Constant orifice mass flow rate vector — Vector of mass flow rates for a constant orifice**

[-.9, 1.6, 2, 2.4] kg/s (default) | 1-by-*n* vector

Vector of mass flow rate values over the valve when the positive, neutral, and negative spool positions use the same orifice. The vector elements correspond one-to-one with the elements in the **P-B Constant orifice pressure drop vector** parameter. The values are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- 1 **Area characteristics** to Different for each flow path.
- 2 **Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 One of the settings in each parameter:

**Positive spool position open connections** to P-A and B-T.

**Neutral spool position open connections** to:

- P-A, P-B, A-T, and B-T
- A-T and B-T
- P-A and B-T
- P-B and B-T
- B-T only
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**Negative spool position open connections** to P-A and B-T.

**P-T Orifice**

**Spool position at maximum P-T orifice area — Spool offset from the neutral position for a fully open P-T orifice**

0 m (default) | positive scalar

Spool offset from the neutral position for a fully open P-T orifice. The **Consistency check for neutral spool position open connections** parameter will notify you if the values set for this spool position are inconsistent or unphysical according to other orifice spool positions.

**Dependencies**

To enable this parameter, set **Neutral spool position open connections** to:

- P-T only
- P-A, A-T, and P-T
- P-B, B-T, and P-T

- P-A, P-B, A-T, B-T, P-T

### **P-T spool travel between closed and open orifice — Maximum spool stroke**

0.005 m (default) | positive scalar

Maximum distance of spool travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3 Neutral spool position open connections** to:
  - P-T only
  - P-A, A-T, and P-T
  - P-B, B-T, and P-T
  - P-A, P-B, A-T, B-T, P-T

### **P-T maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Largest open area of the P-T orifice during the operation of the valve.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Linear - Area vs. spool travel.
- 3 Neutral spool position open connections** to:
  - P-T only
  - P-A, A-T, and P-T
  - P-B, B-T, and P-T
  - P-A, P-B, A-T, B-T, P-T

### **P-T orifice spool travel vector — Vector of spool opening distances relative to fully closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by-*n* vector

Vector of control member travel distances for the tabular parameterization of valve area. The vector elements must correspond one-to-one with the elements in the **P-T orifice area vector** parameter. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Area vs. spool travel.

**3 Neutral spool position open connections** to:

- P-T only
- P-A, A-T, and P-T
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**P-T orifice spool travel vector,  $ds$  — Vector of spool opening distances relative to fully-closed position**

[0, .00125, .0025, .00375, .005] m (default) | 1-by- $n$  vector

Vector of control member travel distances for the tabular parameterization of volumetric flow rate. The spool travel vector forms an independent axis with the **P-T orifice pressure drop vector,  $dp$**  parameter for the 2-D dependent **P-T orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-T orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

**1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Area vs. spool travel.

**3 Neutral spool position open connections** to:

- P-T only
- P-A, A-T, and P-T
- P-B, B-T, and P-T
- P-A, P-B, A-T, B-T, P-T

**P-T orifice pressure drop vector,  $dp$  — Vector of pressure differential values**

[-.1, .3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **P-T orifice spool travel vector,  $ds$**  parameter for the 2-D dependent **P-T orifice volumetric flow rate table,  $q(ds,dp)$**  or **P-T orifice mass flow rate table,  $\dot{m}(ds,dp)$**  parameters. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set:

**1 Area characteristics** to Different for each flow path.

**2 Orifice parameterization** to Tabulated data - Area vs. spool travel.

**3 Neutral spool position open connections** to:

- P-T only
- P-A, A-T, and P-T
- P-B, B-T, and P-T



- P-A, P-B, A-T, B-T, P-T

**P-T orifice volumetric flow rate table,  $q(ds,dp)$  — Array of volumetric flow rates**

$[-1e-08, 2.2e-08, 2.8e-08, 3.4e-08; -9e-06, .00015, .0002, .00024; -0.00036, .00063, .00081, .00096; -0.00054, .00094, .0012, .0014; -0.00091, .0016, .002, .0024]$  m<sup>3</sup>/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-T orifice spool travel vector,  $ds$**  parameter.
- *N* is the number of vector elements in the **P-T orifice pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Area vs. spool travel.
- 3 Neutral spool position open connections** to:
  - P-T only
  - P-A, A-T, and P-T
  - P-B, B-T, and P-T
  - P-A, P-B, A-T, B-T, P-T

**P-T orifice mass flow rate table,  $\dot{m}(ds,dp)$  — Array of mass flow rate values**

$[-1e-05, 1.7e-05, 2e-05, 2.6e-05; -0.009, .0035, .0045, .0053; -0.36, .7, .9, 1.06; -0.54, 1.96, 2.5, 3; -0.91, 6, 7.7, 9.13]$  kg/s (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mass flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the correlated vectors:

- *M* is the number of vector elements in the **P-T orifice pressure drop vector,  $dp$**  parameter.
- *N* is the number of vector elements in the **P-T orifice spool travel vector,  $ds$**  parameter.

**Dependencies**

To enable this parameter, set:

- 1 Area characteristics** to Different for each flow path.
- 2 Orifice parameterization** to Tabulated data - Mass flow rate vs. spool travel and pressure drop.
- 3 Neutral spool position open connections** to:
  - P-T only
  - P-A, A-T, and P-T
  - P-B, B-T, and P-T
  - P-A, P-B, A-T, B-T, P-T

## **Version History**

**Introduced in R2016a**

### **Right-click blocks to view opening characteristic plots**

You can view the plot of the area or volumetric flow rate with respect to spool position for each orifice by right-clicking the block and selecting **Fluids > Plot Valve Characteristics**.

## **Extended Capabilities**

### **C/C++ Code Generation**

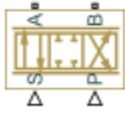
Generate C and C++ code using Simulink® Coder™.

### **See Also**

2-Way Directional Valve (TL) | Orifice (TL) | 3-Way Directional Valve (TL) | Check Valve (TL)

## 4-Way Ideal Valve

Hydraulic 4-way critically-centered valve



### Library

Directional Valves

### Description

The 4-Way Ideal Valve block represents a 4-way critically-centered valve, where initial openings of all four variable orifices are equal to zero. This significantly simplifies the model of a 4-way directional valve and makes it especially suitable for real-time and HIL (hardware-in-the-loop) simulation, where such assumption is applicable.

The flow rate is computed with the equation:

$$q = x C_D b \sqrt{\frac{1}{\rho} (p_S - \text{abs}(p_A - p_B)) \text{sign}(p_A - p_B)}$$

where

$q$	Flow rate
$x$	Valve displacement, $-x_{max} \leq x \leq x_{max}$
$b$	Orifice width, $b = A_{max} / x_{max}$
$A_{max}$	Maximum orifice area
$x_{max}$	Valve maximum opening
$C_D$	Flow discharge coefficient
$\rho$	Fluid density
$p_S$	Pressure supply
$p_A, p_B$	Pressures at the load ports A and B, respectively

Connections A and B are conserving hydraulic ports associated with the valve load ports. Connections P and S are the physical signal input ports that provide supply pressure and valve displacement values, respectively.

### Basic Assumptions and Limitations

- The valve is of a critically-centered type, that is, all initial openings are equal to zero.
- The return pressure is assumed to be very low and can be treated as a zero pressure.

- All the orifices are assumed to have the same shape and size, that is, the valve is symmetrical.

## Parameters

### Valve passage maximum area

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ .

### Valve maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $0.005 \text{ m}$ .

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is  $0.7$ .

## Global Parameters

Parameter determined by the type of working fluid:

- **Fluid density**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the actuator connection port.

B

Hydraulic conserving port associated with the actuator connection port.

P

Physical signal port that controls the supply pressure.

S

Physical signal port that controls spool displacement.

## Examples

The “Closed-Loop Hydraulic Actuator Model for Real-Time Simulation” example is an example of using this valve, along with other blocks optimized for real-time and HIL simulation.

## Version History

**Introduced in R2010a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

4-Way Directional Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## 6-Way Directional Valve A

Configuration A of hydraulic continuous 6-way directional valve



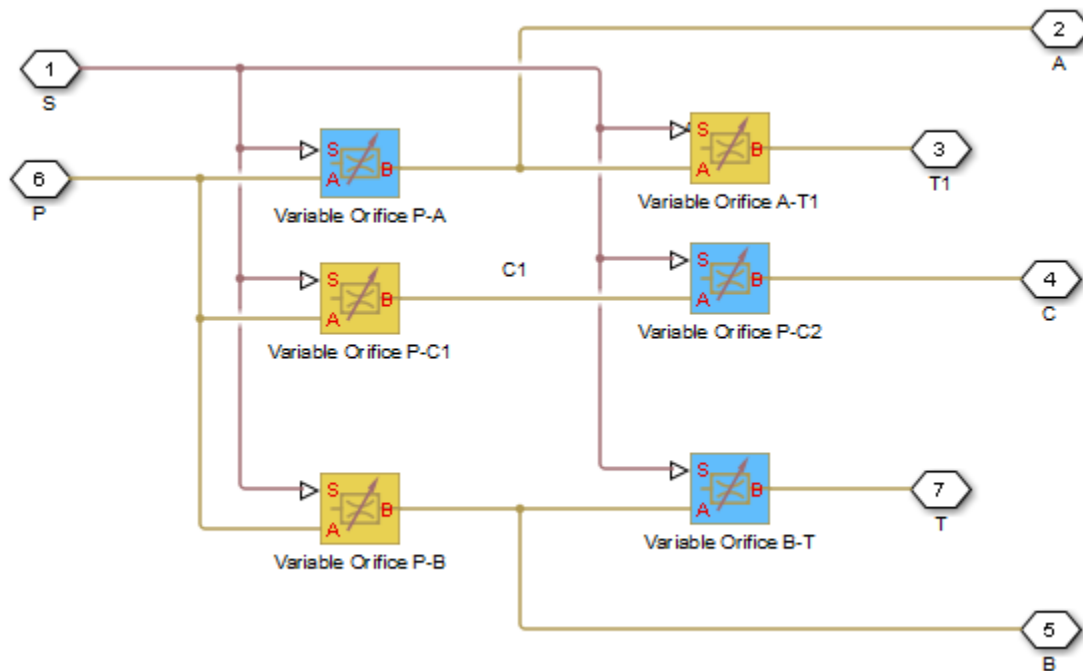
### Library

Directional Valves

### Description

The 6-Way Directional Valve A block simulates a configuration of hydraulic continuous 6-way directional valve with pump port P, two return ports T and T1, and three actuator ports A, B, and C. Use the valve for applications with two actuators, each being controlled by a valve of this type. When both valves are in neutral position, the pump is unloaded. If any of the valves is shifted from neutral, the diverting line is cut off and the respective actuator is fed at fuel pump pressure. For more details, see the “Front-Loader Actuation System” example, which uses a similar system of two valves.

The 6-Way Directional Valve A block has six hydraulic connections, corresponding to the valve hydraulic ports (A, B, C, P, T, and T1), and one physical signal port connection (S), which controls the spool position. The block is built of six Variable Orifice blocks, connected as shown in the following diagram.



All blocks are controlled by the same position signal, provided through the physical signal port S, but the **Orifice orientation** parameter in the block instances is set in such a way that positive signal at port S opens the orifices colored blue in the block diagram (orifices P-A, B-T, and P-C2 ) and closes the orifices colored yellow (orifices A-T1, P-B, and P-C1). As a result, the openings of the orifices are computed as follows:

$$h_{PA} = h_{PA0} + x$$

$$h_{PB} = h_{PB0} - x$$

$$h_{AT1} = h_{AT10} - x$$

$$h_{BT} = h_{BT0} + x$$

$$h_{PC1} = h_{PC10} - x$$

$$h_{PC2} = h_{PC20} + x$$

where

$h_{PA}$	Orifice opening for the Variable Orifice P-A block
$h_{PB}$	Orifice opening for the Variable Orifice P-B block
$h_{AT1}$	Orifice opening for the Variable Orifice A-T1 block
$h_{BT}$	Orifice opening for the Variable Orifice B-T block
$h_{PC1}$	Orifice opening for the Variable Orifice P-C1 block
$h_{PC2}$	Orifice opening for the Variable Orifice P-C2 block
$h_{PA0}$	Initial opening for the Variable Orifice P-A block
$h_{PB0}$	Initial opening for the Variable Orifice P-B block
$h_{AT10}$	Initial opening for the Variable Orifice A-T1 block
$h_{BT0}$	Initial opening for the Variable Orifice B-T block
$h_{PC10}$	Initial opening for the Variable Orifice P-C1 block
$h_{PC20}$	Initial opening for the Variable Orifice P-C2 block
$x$	Control member displacement from initial position

For information on the block parameterization options, basic parameter descriptions, assumptions and limitations, global and restricted parameters, see the 4-Way Directional Valve block reference page.

## Parameters

- “Basic Parameters Tab” on page 1-369
- “Valve Opening Offsets Tab” on page 1-372

### Basic Parameters Tab

#### Model parameterization

Select one of the following methods for specifying the valve:

- **By maximum area and opening** — Provide values for the maximum valve passage area and the maximum valve opening. The passage area is linearly dependent on the control member displacement, that is, the valve is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of valve openings and corresponding valve passage areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of valve openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

#### **Valve passage maximum area**

Specify the area of a fully opened valve. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve maximum opening**

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

#### **Valve opening vector, s**

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated valve openings** values will be used together with **Tabulated valve passage area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

#### **Valve passage area vector**

Specify the vector of output values for valve passage area as a one-dimensional array. The valve passage area vector must be of the same size as the valve openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

#### **Pressure differential vector, dp**

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

#### **Volumetric flow rate table, q(s,dp)**

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of valve openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $\text{m}^3/\text{s}$ , are:



```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the valve, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with

sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### Valve Opening Offsets Tab

#### Between ports P and A

Orifice opening of the **P-A** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### Between ports P and B

Orifice opening of the **P-B** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### Between ports A and T1

Orifice opening of the **A-T1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### Between ports B and T

Orifice opening of the **B-T** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $-2.5e-3 \text{ m}$ .

#### Between ports P and C1

Orifice opening of the **P-C1** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

#### Between ports P and C2

Orifice opening of the **P-C2** flow path at zero spool displacement. Specify a positive offset to model an underlapped valve or a negative offset to model an overlapped valve. The default value of  $\theta$  corresponds to a zero-lapped valve. The default value is  $2.5e-3 \text{ m}$ .

## Ports

The block has the following ports:

P

Hydraulic conserving port associated with the pressure supply line inlet.

T

Hydraulic conserving port associated with the first return line connection.

T1

Hydraulic conserving port associated with the second return line connection.

- A Hydraulic conserving port associated with the actuator connection port.
- B Hydraulic conserving port associated with the actuator connection port.
- C Hydraulic conserving port associated with the actuator connection port.
- S Physical signal port to control spool displacement.

## Version History

Introduced in R2009b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

4-Way Directional Valve | 4-Way Directional Valve A | 4-Way Directional Valve B | 4-Way Directional Valve C | 4-Way Directional Valve D | 4-Way Directional Valve E | 4-Way Directional Valve F | 4-Way Directional Valve G | 4-Way Directional Valve H | 4-Way Directional Valve K

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Air Muscle Actuator (G)

Linear actuator with force characteristics of biological muscle

**Library:** Simscape / Fluids / Gas / Actuators



### Description

The Air Muscle Actuator (G) block models a linear actuator popular in robotics for its characteristics reminiscent of biological muscle. The actuator comprises an expandable bladder in a braided shell. When the bladder is pressurized, the pair widens and simultaneously shortens, producing at their end caps a contractile force. The bladder is pressurized at Gas port **A**; the force is exerted at Mechanical Translational ports **R** and **C**.



### Air Muscle in Relaxed State

Air muscles are often installed in pairs—one muscle serving as agonist, the other as antagonist. Pairs of this sort are common in the human body, where the biceps (in the arm) accompanies the triceps, and the quadriceps (in the leg) accompanies the hamstrings. The muscles attach at one end to a joint, but at an offset so as to produce a torque. When the net torque is other than zero, and if loading conditions allow, the joint rotates.

### Actuator Force

The mass and energy balances of the actuator are as described for the Translational Mechanical Converter (G) block. The actuator force, however, is based on the standard Chou-Hannaford equation (with two corrections made for the simplifying assumptions of the original model). In its original form, the Chou-Hannaford equation gives:

$$F_{C-H} = \frac{\pi D_M^2 P}{4} \left[ 3 \left( \frac{L}{l} \right)^2 - 1 \right],$$

where:

- $F$  is the contractile force exerted by the actuator on its ends. The subscript C-H denotes the theoretical value of the original Chou-Hannaford model.
- $D$  is the diameter of the bladder and shell assembly. The subscript M denotes its maximum theoretical value—that in which the braids of the shell are at right angles to its longitudinal axis.
- $P$  is the gauge pressure in the bladder (measured against the environment external to the actuator).
- $L$  is the length of the actuator (the distance between the mechanical ports **R** and **C**).

- $l$  is the natural length of a braid (before it is stretched in a pressurized bladder). The braids, as they are wound about the longitudinal axis of the actuator, are always longer than the actuator itself).

The maximum theoretical diameter of the actuator is defined as:

$$D_M = \frac{l}{n\pi},$$

where  $n$  is the number of turns that a braid makes about the longitudinal axis of the actuator.

Implicit in the Chou-Hannaford equation are the assumptions of infinitely thin bladder and shell and of inelastic braids incapable of stretching. Both assumptions can lower the accuracy of the model and are corrected for in this block. The correction for the stretching in a braid replaces the constant length  $l$  with the variable length  $l^*$ :

$$l^* = \frac{Cl + \sqrt{(Cl)^2 + 12L^2(C + 1)}}{2(C + 1)} + \frac{2nPD^2}{Ed},$$

where  $l$  is the natural length of a braid used in the original Chou-Hannaford equation and:

- $C$  is a correction term for braid stretching.
- $E$  is Young's modulus of elasticity for the material of the braids.
- $d$  is the diameter of a strand in a braid (each braid being a bundle of tightly intertwined strands).

The correction term for braid stretching is defined as:

$$C = \frac{n^2\pi^2Ed^2N}{PlL},$$

where  $N$  is the total number strands in the braided shell. The correction for the thickness of the bladder and shell adds to the total actuator force the factor:

$$F_T = \pi P \left[ t \left( 2D - \frac{D_M^2}{D} \right) - t^2 \right]$$

where  $t$  is the aggregate thickness of the bladder and shell and the subscript T denotes the correction for thickness. The total actuator force is:

$$F = F_{H-F} + F_T,$$

where the strand length used in the calculation of the Chou-Hannaford term is the variable  $l^*$ . This force is counteracted at the limits of extension and contraction by translational hard stops. These are modeled as described for the Translational Hard Stop block.

### Modeling Assumptions

- There is no flow resistance between the gas entrance (port **A**) and the interior of the actuator.
- There is no thermal resistance between the actuator wall (port **H**) and the gas that it encloses.
- The actuator is hermetic and does not leak.
- The effects of friction and inertia are ignored.
- The bladder and shell are perfectly cylindrical no matter their inflation level.

- The longitudinal elasticity of the bladder is ignored.

## Ports

### Conserving

#### A — Actuator inlet

gas

Gas opening for pressurizing the actuator. Connect this port to the pressure source for the actuator. The pressure at this port controls the force generated by the actuator.

#### R — Actuator end cap

mechanical translational

One of two end caps at which the actuator force is applied. Connect this port to the fixture on which the actuator is to be mounted or to the load that the actuator is to move.

#### C — Actuator end cap

mechanical translational

One of two end caps at which the actuator force is applied. Connect this port to the fixture on which the actuator is to be mounted or to the load that the actuator is to move.

#### H — Actuator wall

thermal

Thermal boundary condition between the gas volume of the actuator and its surroundings. Connect this port to blocks in the Thermal domain to capture heat transfer by conduction, convection, or radiation, for example, or to insulate the actuator from the environment.

## Parameters

### **Initial actuator length — Distance between end caps when unloaded and unpressurized**

0.575 m (default) | positive scalar in units of length

Distance between the end caps of the actuator in the relaxed state, when it is both unloaded and unpressurized. Inflating the actuator during simulation causes it to widen and simultaneously to shorten. The actuator is shorter than its braids, which is to say that its initial length should be less than the **Unstretched braid length** parameter.

### **Unstretched braid length — Length of straightened braid when unloaded**

0.65 m (default) | positive scalar in units of length

Length of a braid as measured with its turns straightened and any loads removed. If the braids are elastic, their (common) length will vary with during simulation pressure and load. As the braids are wound about the longitudinal axis of the actuator, their length is always greater than the **Initial actuator length** parameter.

### **Number of turns per braid — Number of turns in a braid about the actuator length axis**

4.7 (default) | positive unitless scalar

Number of turns that a braid makes about the longitudinal axis of the actuator from one end cap to the second.

### **Braid stretching — Choice of whether to model the stretching of a braid**

Inelastic braids (default) | Elastic braids

Choice of whether to model the stretching of a braid. The default option, `Inelastic braids`, treats the braids as flexible but inextensible. This is the assumption implicit in the original Chou-Hannaford equation. The length of a braid is then constant during simulation.

The alternative option, `Elastic braids`, allows the braids to extend with actuator load and pressure. The length of the braid is then treated as variable during simulation. This change adds a correction to the Chou-Hannaford equation for force.

### **Thickness of braided shell and bladder — Combined thickness of shell and bladder**

0.075 m (default) | positive scalar in units of length

Sum of the thicknesses of the braided shell and of the bladder inside it. A finite thickness adds to the Chou-Hannaford equation for force a correction term. (In the original Chou-Hannaford equation, the shell and bladder are assumed to be infinitely thin.)

### **Cross-sectional area at port A — Area normal to flow at the gas port**

0.01 m (default) | positive scalar in units of length

Area normal to flow at the gas port of the actuator.

### **Total number of braids — Number of braids in the braided shell**

80 (default) | positive unitless scalar

Number of braids in the shell surrounding the bladder. As the braids are each a bundle of intertwined strands, the number of braids is not generally the same as the number of strands.

#### **Dependencies**

This parameter is active when the **Braid stretching** option is set to `Elastic Braids`.

### **Number of strands per braid — Number of individual strands in a braid**

3 (default) | positive unitless scalar

Number of strands in a braid. The product of this number and the **Total number of braids** parameter gives the total number of strands in the shell.

#### **Dependencies**

This parameter is active when the **Braid stretching** option is set to `Elastic Braids`.

### **Strand diameter — Diameter of a strand**

0.25 m (default) | positive scalar in units of length

Average diameter of a strand throughout its length.

#### **Dependencies**

This parameter is active when the **Braid stretching** option is set to `Elastic Braids`.

### **Young's modulus of strands — Degree to which the strands extend under pressure**

3e9 GPA (default)

Young's modulus of elasticity for the material of the strands. This parameter determines the degree to which the strands extend under pressure.

**Dependencies**

This parameter is active when the **Braid stretching** option is set to `Elastic Braids`.

**Environment pressure specification — Pressure condition outside of the actuator**

`Atmospheric pressure (default) | Specified pressure`

Pressure condition in the immediate surroundings of the actuator. The gauge pressure in the actuator is obtained relative to this pressure. Select `Atmospheric pressure` to use the atmospheric value specified in the Two-Phase Fluid Properties (2P) block or `Specified pressure` to use a different pressure.

**Environment pressure — Absolute pressure outside of the actuator**

`0.101325 (default) | scalar in units of pressure`

Absolute pressure in the immediate surroundings of the actuator. The actuator contracts when the gauge pressure at port **A** (measured against this value) is greater than zero.

**Dependencies**

This parameter is active when the **Environment pressure specification** option is set to `Specified pressure`.

**Contact stiffness of braids at full muscle contraction or extension — Stiffness coefficient for contact force at actuator motion limits**

`1e6 N/m (default)`

Stiffness coefficient for the contact force at the limits of the actuator's range of motion. The contact force keeps the actuator from extending or contracting beyond its physical limits. The contact force is modeled using a spring-damper system. The spring element adds a restorative force that pulls the end caps back once they reach either limit of motion.

For more information on the force model, see the Translational Hard Stop block.

**Contact damping of braids at full muscle contraction or extension — Damping coefficient for contact force at actuator motion limits**

`1e4 N/(m/s) (default)`

Damping coefficient for the contact force at the limits of the actuator's range of motion. The contact force keeps the actuator from extending or contracting beyond its physical limits. This force is modeled using a spring-damper system. The damper adds a viscous force to the end caps once they reach a limit of motion, causing them to slow to a stop.

For more information on the force model, see the Translational Hard Stop.

## Version History

Introduced in R2018b



## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Fan (G) | Translational Mechanical Converter (G) | Translational Hard Stop

# Angle Sensor

Ideal angle sensor with measuring range from 0 to 360 degrees



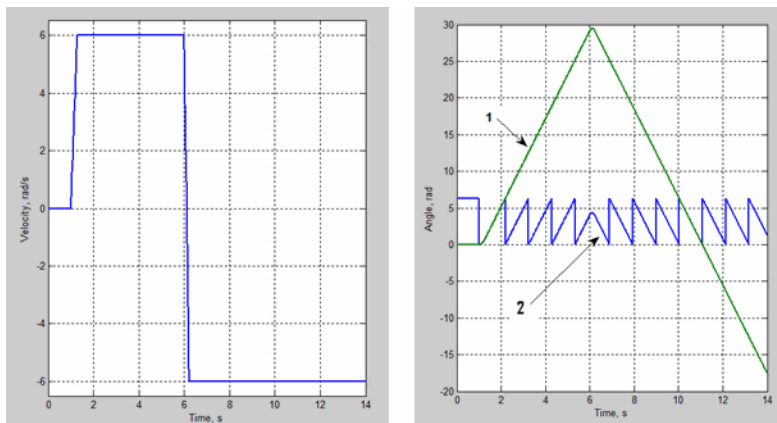
## Library

Pumps and Motors

## Description

The Angle Sensor block represents an ideal angle sensor with measuring range from 0 to 360 degrees. To measure an angular displacement, the sensor must be connected to a mechanical rotational port. No load is imposed on the measured object. The sensor output is kept within the range from 0 to  $2\pi$  radians (360 degrees) regardless of the number of revolutions performed by the object and the direction of rotation. The sensor is ideal because it does not account for inertia, friction, and so on.

The difference between the Angle Sensor block and the Ideal Rotational Motion Sensor block, available in the Simscape Foundation library, is demonstrated in the following figure.



In this example, the object is moving at 6 rad/s in the positive direction for the first 5 seconds, and then switches to the negative direction at the same speed. The Ideal Rotational Motion Sensor block output (line 1) shows that the object turned forward by 30 rad and then turned back in the negative direction, continuing until -20 rad. The reading of the Angle Sensor block (line 2) stays in the range from 0 to  $2\pi$  rad.

Availability of the Angle Sensor block considerably simplifies development of models with complex relationship between model parameters and rotation angle, such as pumps and motors.

## Basic Assumptions and Limitations

- The sensor is assumed to be ideal. No load is imposed on the object.
- No inertial effects are considered.

## Parameters

### Phase angle

This parameter lets you account for angular shift between the object and the sensor input. The default value is 0.

## Ports

The block has the following ports:

W

Mechanical rotational conserving port associated with the probe of the sensor.

A

Physical signal port that outputs the angular displacement of the object.

## Examples

The “Hydraulic Axial-Piston Pump with Load-Sensing and Pressure-Limiting Control” example models a test rig designed to investigate interaction between an axial-piston pump and a typical control unit, simultaneously performing the load-sensing and pressure-limiting functions. To assure required accuracy, the model of the pump must account for such features as interaction between pistons, swash plate, and porting plate, which makes it necessary to build a detailed pump model.

The Angle Sensor block is used in each of the piston model subsystems (`Piston_1`, ..., `Piston_5`), where it provides the angular position of the respective piston as input to the Porting Plate Variable Orifice blocks.

## Version History

Introduced in R2011a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Ideal Rotational Motion Sensor

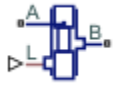
### Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Annular Leakage (IL)

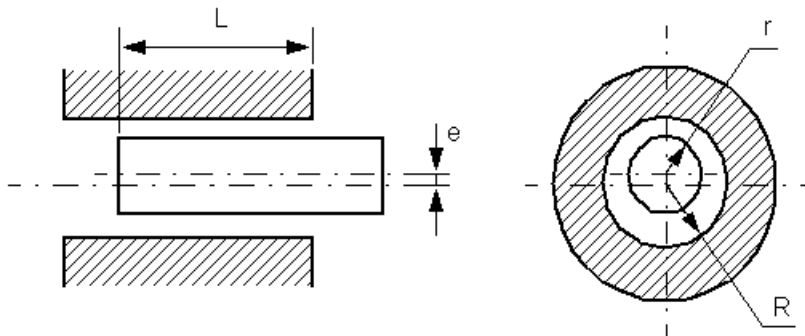
Models annular leakage between a circular tube and a round insert in an isothermal flow

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Orifices



### Description

The Annular Leakage (IL) block models annular leakage between a circular tube and a round insert in an isothermal liquid network. The insert can be located off-center from the tube and can have varying lengthwise overlap with the tube.



Ports **A** and **B** correspond with the orifice inlet and outlet. The input ports **L** and **E** are optional physical signal ports that model variable overlap length ( $L$ ) and variable eccentricity ( $E$ ).

### The Mass Flow Rate Equation

The leakage mass flow rate is calculated from the pressure-flow rate equation

$$\dot{m} = \frac{\pi(R-r)^3(R+r)}{12\nu} \frac{(p_A - p_B)}{l} \left[ 1 + 3\varepsilon_{sat}^2 \frac{R}{(R+r)} + \frac{3}{8} \varepsilon^4 \frac{(R-r)}{(R+r)} \right],$$

where:

- $R$  is the annulus outer radius.
- $r$  is the annulus inner radius.
- $p_A$  is the pressure at port **A**.
- $p_B$  is the pressure at port **B**.
- $\nu$  is the fluid kinematic viscosity.
- $l$  is the overlap length.

- $\varepsilon$  is the eccentricity ratio,  $\varepsilon = \frac{e}{R-r}$ , where  $e$  is the eccentricity, which can be defined as a physical signal or constant value.
- $\varepsilon_{\text{sat}}$  is the saturated eccentricity ratio, which is  $\varepsilon$  for constant orifices, or the physical signal connected to port **L** for variable orifices. The eccentricity ratio is always between 0 and 1.

When modeling a variable overlap length, the user-defined minimum overlap length is used if the physical signal falls below the value of the **Minimum overlap length** parameter.

### Assumptions and Limitations

The pressure-flow equation is valid only for fully-developed, laminar flows. The flow Reynolds number can be determined using  $Re = \frac{\dot{m}D_h}{\mu\pi(R^2 - r^2)}$  or by checking the simulation log in the Results Explorer or the Simulation Data Inspector. For more information, see “Data Logging”.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the orifice.

#### B – Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the orifice.

### Input

#### L – Variable overlap length

physical signal

Optional physical signal port that provides the variable overlap length between the sleeve and annular insert.

#### Dependencies

To expose this port, set **Overlap length specification** to Variable.

#### E – Variable eccentricity

physical signal

Optional physical signal port that provides variable eccentricity of the annular insert to the sleeve.

#### Dependencies

To expose this port, set **Eccentricity specification** to Variable.

## Parameters

### **Overlap length specification — Type of insert-sleeve overlap**

Constant (default) | Variable

Whether the length-wise sleeve-insert overlap is constant or variable.

### **Overlap length — Overlap between tube and insert**

$1e-3$  m (default) | positive scalar

Length-wise overlap between the insert and tube.

#### **Dependencies**

To enable this parameter, set **Overlap length specification** to Constant.

### **Minimum overlap length — Minimum overlap between tube and insert**

$1e-6$  m (default) | positive scalar

Lower limit to the length-wise overlap between the insert and tube. Any length shorter than this value will be set to the specified minimum.

#### **Dependencies**

To enable this parameter, set **Overlap length specification** to Variable.

### **Eccentricity specification — Eccentricity variability**

Constant (default) | Variable

Whether the orifice eccentricity changes or remains at a set value.

### **Eccentricity — Center of insert offset with respect to sleeve center**

$0$  m (default) | positive scalar

The distance between the center of the orifice and the center of the insert.

#### **Dependencies**

To enable this parameter, set **Eccentricity specification** to Constant.

### **Inner radius — Radius of insert**

$9.8e-3$  m (default) | positive scalar

Insert radius  $r$ .

### **Outer radius — Radius of tube**

$1e-2$  m (default) | positive scalar

Tube radius  $R$ , measured from the tube center to the inner wall.

## Version History

Introduced in R2020a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

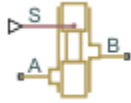
### **See Also**

Orifice (IL) | Spool Orifice (IL) | Variable Overlapping Orifice (IL)

## Annular Orifice

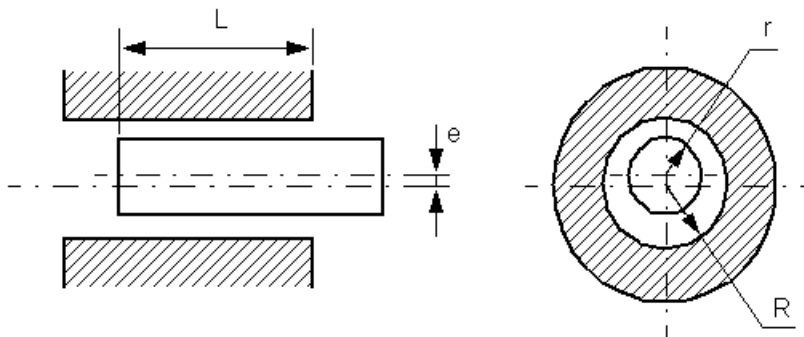
Hydraulic variable orifice created by circular tube and round insert

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Orifices



### Description

The Annular Orifice block annular leakage in a fully-developed laminar flow created by a circular tube and a round insert in an isothermal liquid network. The insert can be located off-center from the tube by an eccentricity value.



The flow rate is computed using the Hagen-Poiseuille equation (see [1]):

$$q = \frac{\pi R(R-r)^3}{6\nu\rho L} \cdot \left(1 + \frac{3}{2}\varepsilon^2\right) \cdot p$$

$$\varepsilon = \frac{e}{R-r}$$

where

$q$	Flow rate
$p$	Pressure differential
$R$	Orifice radius
$r$	Insert radius
$L$	Overlap length
$\varepsilon$	Eccentricity ratio
$e$	Eccentricity



$\rho$	Fluid density
$\nu$	Fluid kinematic viscosity

Use this block to simulate leakage path in plungers, valves, and cylinders.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S increases or decreases the overlap, depending on the value of the parameter **Orifice orientation**.

## Assumptions and Limitations

Fluid inertia is not taken into account.

## Ports

### Input

**S – Physical signal port that controls the insert displacement, m**  
physical signal

Physical signal port that controls the insert displacement.

### Conserving

**A – Hydraulic conserving port associated with the orifice inlet**  
hydraulic

Hydraulic conserving port associated with the orifice inlet.

**B – Hydraulic conserving port associated with the orifice outlet**  
hydraulic

Hydraulic conserving port associated with the orifice outlet.

## Parameters

**Orifice radius – Radius of the tube**  
0.01 m (default) | positive scalar

The radius of the tube.

**Insert radius – Radius of the insert**  
0.0098 m (default) | positive scalar

The radius of the insert.

**Eccentricity – Distance between the central axes of the insert and the tube**  
0 (default) | nonnegative scalar

The distance between the central axes of the insert and the tube. The parameter can be a positive value, smaller than the difference between the radius of the tube and the radius of the insert, or equal to zero for coaxial configuration.

**Initial length — Initial overlap between the tube and the insert**

0.003 m (default) | positive scalar

Initial overlap between the tube and the insert. The parameter must be positive. The value of the initial length does not depend on the orifice orientation.

**Orifice orientation — Specifies the effect of the control signal on the orifice overlap**

Positive signal increases overlap (default) | Negative signal increases overlap

Specifies the effect of the control signal on the orifice overlap.

## Version History

Introduced in R2006b

## References

[1] Noah D. Manring, *Hydraulic Control Systems*, John Wiley & Sons, 2005

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Constant Area Hydraulic Orifice | Fixed Orifice | Orifice with Variable Area Round Holes | Orifice with Variable Area Slot | Variable Area Hydraulic Orifice | Variable Orifice

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Area Change (IL)

Area expansion or contraction along a pipe in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Area Change (IL) block models a sudden or a gradual area change along a pipe with fixed areas and variable flow direction. When the fluid moves from port **A** to port **B**, it experiences an area contraction. When the fluid flows from port **B** to port **A**, it experiences an area expansion. The inlet and outlet areas can be equal.

Both semi-empirical and tabular formulations are available for correlating flows to losses.

### Semi-Empirical Formulation

In the semi-empirical, analytical formulation, losses in pressure and velocity are characterized by a *Hydraulic loss coefficient*,  $K$ , in terms of a user-defined **Contraction correction factor**,  $C_{\text{contraction}}$ , and **Expansion correction factor**,  $C_{\text{expansion}}$ , from Crane [1]. The coefficient that characterizes area change is calculated from both expansion and contraction loss factors and based on the flow rate through the block.

For gradual conical area contractions between 0 and 45 degrees, the contraction loss factor is:

$$K_{\text{contraction}} = 0.8C_{\text{contraction}}\sin\left(\frac{\theta}{2}\right)(1 - R),$$

where  $R$  is the port area ratio  $\frac{A_{\text{smaller}}}{A_{\text{bigger}}}$ . For gradual area contraction between 45 and 180 degrees:

$$K_{\text{contraction}} = \frac{C_{\text{contraction}}}{2}\sqrt{\sin\left(\frac{\theta}{2}\right)}(1 - R),$$

where  $\theta$  is the **Cone angle**. A sudden area change has an angle of 180 degrees. In this case, the loss factor is calculated as  $K_{\text{contraction}} = \frac{C}{2}(1 - R)$ .

For gradual conical area expansions between 0 and 45 degrees, the expansion loss factor is:

$$K_{\text{expansion}} = 2.6C_{\text{expansion}}\sin\left(\frac{\theta}{2}\right)(1 - R)^2,$$

and for gradual area expansion between 45 and 180 degrees:

$$K_{\text{expansion}} = C_{\text{expansion}}(1 - R)^2.$$

The hydraulic loss coefficient for the pipe change segment is calculated from these values as:

$$K = K_{\text{expansion}} + \frac{K_{\text{contraction}} - K_{\text{expansion}}}{2}\left(\tanh\left(\frac{3\dot{m}_A}{\dot{m}_{th}}\right) + 1\right),$$

where:

- $\dot{m}_A$  is the mass flow rate through port **A**. Mass is conserved through the segment:  $\dot{m}_A + \dot{m}_B = 0$ .
- $\dot{m}_{th}$  is the threshold mass flow rate for flow reversal, which is based on the **Critical Reynolds number**,  $Re_c$ :

$$\dot{m}_{th} = \frac{Re_c A_R \nu \bar{\rho}}{D_h},$$

where:

- $A_R$  is the smallest segment area (either the **Cross-sectional area at port A** or the **Cross-sectional area at port B**.)
- $\nu$  is the fluid kinematic viscosity.
- $\bar{\rho}$  is the average fluid density.
- $D_h$  is the hydraulic diameter at  $A_R$ :  $D_h = \sqrt{\frac{4A_R}{\Pi}}$ .

### Tabulated Data Parameterization

The loss factor can also be parameterized with user-provided data interpolated from the Reynolds number at the smallest area, which in turn is a function of the **Critical Reynolds number**:

$$K = TLU(Re_c).$$

Linear interpolation is employed between data points, and nearest-neighbor extrapolation is employed beyond the table boundaries.

### Pressure Differential

The pressure differential over the area change is

$$p_A - p_B = \frac{\dot{m}^2}{2\bar{\rho}A_R^2}(1 - R^2) + \Delta p_{loss},$$

where the pressure loss is:

$$\Delta p_{loss} = \frac{K}{2\bar{\rho}A_R^2} \dot{m}_A \sqrt{\dot{m}_A^2 + \dot{m}_{th}^2}.$$

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry port.

#### B — Liquid port

isothermal liquid

Liquid exit port.

## Parameters

### Cone angle — Gradual area change angle

30 (default) | positive scalar

Angle of expansion for a gradual area change parameterized as a cone.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Semi-empirical correlation - gradual area change.

### Local loss parameterization — Model of hydraulic losses

Semi-empirical correlation - sudden area change (default) | Semi-empirical correlation - gradual area change | Tabulated data - loss coefficient vs. Reynolds number

Model of hydraulic losses due to area change. You can choose from two analytical, semi-empirical formulations or you can provide your own data by selecting Tabulated data - loss coefficient vs. Reynolds number.

### Cross-sectional area at port A — Area at port A

0.02 m<sup>2</sup> (default) | positive scalar

Area at the section entrance, port **A**.

### Cross-sectional area at port B — area at port B

0.01 m<sup>2</sup> (default) | positive scalar

Area at the section exit, port **B**.

### Reynolds number vector — Vector of Reynolds number values for tabular parameterization

[10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000] (default) | 1-by-*n* vector

Vector of Reynolds number values for the tabular parameterization of the area change. The elements must correspond one-to-one with the elements of the **Contraction loss coefficient vector** and the **Expansion loss coefficient vector** parameters. The vector values are listed in ascending order.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

### Contraction loss coefficient vector — Vector of loss coefficients for an area contraction

[5, 2.7, 1.8, 1.46, 1.3, .9, .65, .42, .3, .2] (default) | 1-by-*n* vector

Vector of loss coefficients for an area contraction corresponding to the **Reynolds number vector** parameter, where *n* is the length of the **Reynolds number vector**. The elements are listed in descending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Expansion loss coefficient vector – Vector of loss coefficients for an area expansion**  
[3.1, 2.3, 1.65, 1.35, 1.15, .9, .75, .65, .9, .65] (default) | 1-by- $n$  vector

Vector of loss coefficients for an area expansion corresponding to the **Reynolds number vector** parameter, where  $n$  is the length of the **Reynolds number vector**. The elements are listed in descending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Expansion correction factor – Coefficient in semi-empirical loss factor equation**  
1 (default) | positive scalar

Coefficient used in the semi-empirical calculation of the area expansion loss factor.

**Dependencies**

To enable this parameter, set **Local loss parameterization** to either:

- Semi-empirical correlation - sudden area change
- Semi-empirical correlation - gradual area change

**Contraction correction factor – Coefficient in semi-empirical loss factor equation**  
1 (default) | positive scalar

Coefficient used in the semi-empirical calculation of the area contraction loss factor.

**Dependencies**

To enable this parameter, set **Local loss parameterization** to either:

- Semi-empirical correlation - sudden area change
- Semi-empirical correlation - gradual area change

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**  
150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

## Version History

Introduced in R2020a

## References

- [1] *Flow of Fluids Through Valves, Fittings, and Pipe*, Crane Valves North America, Technical Paper No. 410M

[2] Idelchik, I.E., *Handbook of Hydraulic Resistance*, CRC Begell House, 1994

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Pipe Bend (IL) | Elbow (IL) | Local Resistance (IL) | T-Junction (IL)

## Ball Valve

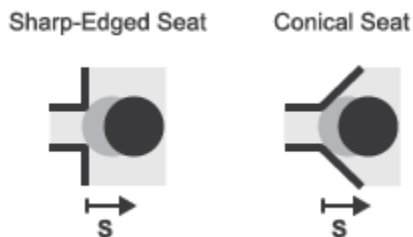
Valve with a sliding ball control mechanism

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Flow Control Valves



### Description

The Ball Valve block models an orifice with a variable opening area controlled by a sliding ball mechanism. The opening area changes with the relative position of the ball—the *valve lift*. A displacement toward the orifice decreases flow while a displacement away increases flow. The interface between the orifice and the ball—the *valve seat*—can be **Sharp-edged**, shown left in the figure, or **Conical**, shown right.



### Ball Valve Seat Types

#### Opening Area

The valve lift is a function of the displacement signal specified through port **S**. The two can, but generally do not, have the same value. The valve lift differs from the displacement whenever the **Ball displacement offset** parameter is nonzero:

$$h(x) = x_0 + s,$$

where:

- $h$  is the valve lift.
- $x_0$  is the ball displacement offset.
- $s$  is the ball displacement (relative to the specified offset).

The valve is fully closed when the valve lift is equal to zero or less. It is fully open when the valve lift reaches or exceeds a (geometry-dependent) value sufficient to completely clear the orifice. A fully closed valve has an opening area equal to the specified **Leakage area** parameter while a fully open valve has the maximum possible opening area. Adjusting for internal leakage:

$$A_{Max} = \pi r_0^2 + A_{Leak},$$

where:



- $A_{\text{Max}}$  is the maximum opening area.
- $r_o$  is the orifice radius.
- $A_{\text{Leak}}$  is the internal leakage area between the ports.

At intermediate values of the valve lift, the opening area depends on the valve seat geometry. If the **Valve seat specification** parameter is set to Sharp-Edged, the opening area as a function of valve lift is:

$$A(h) = \pi r_o \left( 1 - \left[ \frac{r_B}{d_{OB}} \right]^2 \right) d_{OB}(h),$$

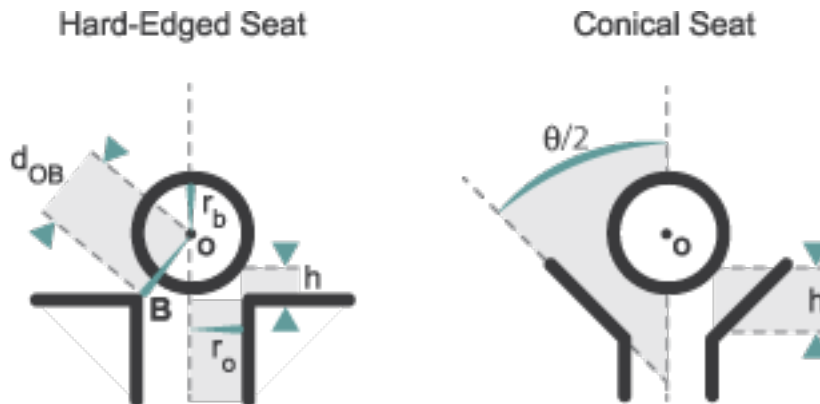
where:

- $A$  is the opening area at a given valve lift value.
- $r_B$  is the ball radius.
- $d_{OB}(h)$  is the distance from the center of the ball (point **O** in the figure) to the edge of the orifice (point **B**). This distance is a function of the valve lift ( $h$ ).

If the **Valve seat specification** parameter is set to Conical, the opening area becomes:

$$A(h) = \pi h \cos(\theta) \sin(\theta) \cdot (2r_B + h \sin(\theta)),$$

where  $\theta$  is the angle between the conical surface and the orifice centerline. The geometrical parameters and variables used in the equations are shown in the figure.



## Valve Geometries

### Flow Rate

The volumetric flow rate through the valve is a function of the opening area,  $A(h)$ , and of the pressure differential between the valve ports:

$$q = C_D A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p)^2 + p_{Cr}^2}}^{1/4},$$

where:

- $C_D$  is the flow discharge coefficient.

- $\rho$  is the hydraulic fluid density.
- $\Delta p$  is the pressure differential between the valve ports, defined as:

$$\Delta p = p_A - p_B,$$

where  $p_A$  is the pressure at port **A** and  $p_B$  is the pressure at port **B**.

- $p_{Cr}$  is the minimum pressure required for turbulent flow.

The critical pressure  $p_{Cr}$  is computed from the critical Reynolds number as:

$$p_{Cr} = \frac{\rho}{2} \left( \frac{Re_{Cr} \nu}{C_D D_H} \right)^2,$$

where:

- $Re_{Cr}$  is the critical Reynolds number.
- $\nu$  ( $nu$ ) is the hydraulic fluid dynamic viscosity.
- $D_H$  is the orifice hydraulic diameter:

$$D_H = \begin{cases} D_H^{Min}, & \text{if } h \leq 0 \\ D_H^{Max} + D_H^{Min}, & \text{if } h \geq h_{Max}, \\ \frac{4A}{l} + D_H^{Min}, & \text{otherwise} \end{cases}$$

in which:

- $D_H^{Min}$  is the minimum hydraulic diameter, corresponding to the smallest attainable flow area, the leakage flow area.
- $D_H^{Max}$  is the maximum hydraulic diameter, corresponding to the largest attainable flow area, that of the valve in the fully open position.
- $l$  is the wetted length of the valve perimeter—which can, but need not, be that of a circle.

## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Assumptions

Fluid inertia is assumed to be negligible.

## Ports

### Input

#### **S – Ball displacement, m**

physical signal

Physical signal input port for the ball displacement.

### Conserving

#### **A – Valve inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the valve inlet.

#### **B – Valve outlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the valve outlet.

## Parameters

#### **Valve seat specification – Valve seat geometry type**

Sharp-edged (default) | Conical

Geometry of the valve seat. The choice of geometry impacts the opening characteristics of the valve. See the block description for the valve opening calculations.

#### **Cone angle – Angle between sloping edges of transverse seat cross section**

120 deg (default) | scalar in units of rotation

Angle between the sloping edges of the seat in a transverse cross-sectional view.

#### **Ball diameter – Diameter of the ball control element**

0.01 m (default) | scalar in units of length

Diameter of the ball control element. This diameter must be greater than that specified for the orifice.

#### **Orifice diameter – Diameter of the valve orifice**

0.005 m (default) | scalar in units of length

Diameter of the valve orifice. This diameter must be smaller than that specified for the ball control element.

#### **Ball displacement offset – Neutral position of ball control element**

0 m (default) | scalar in units of length

Neutral position of the ball control element. The neutral position is that to which the ball returns when the displacement signal is zero. This parameter must be greater than or equal to zero.

#### **Discharge coefficient – Semi-empirical parameter for valve capacity characterization**

0.7 (default) | unitless scalar between 0 and 1

Ratio of the actual and theoretical flow rates through the valve. This parameter depends on the geometrical properties of the valve. Values are usually provided in textbooks and manufacturer data sheets.

**Leakage area — Internal leakage area between valve inlets**

1e-12 m<sup>2</sup> (default) | positive scalar in units of area

Total area of internal leaks in the completely closed state. The purpose of this parameter is to maintain the numerical integrity of the fluid network by preventing a portion of that network from becoming isolated when the valve is completely closed.

**Laminar transition specification — Choice of parameter used to define the laminar-turbulent transition**

Pressure ratio (default) | Reynolds number

Select the parameter to base the laminar-turbulent transition on. Options include:

- **Pressure ratio** — Flow transitions between laminar and turbulent at the pressure ratio specified in the **Laminar flow pressure ratio** parameter. Use this option for the smoothest and most numerically robust flow transitions.
- **Reynolds number** — The transition occurs at the Reynolds number specified in the **Critical Reynolds number** parameter. Flow transitions are more abrupt and can cause simulation issues at near-zero flow rates.

**Laminar flow pressure ratio — Pressure ratio at the laminar-turbulent flow transition**

0.999 (default) | unitless scalar between 0 and 1

Pressure ratio at which the flow transitions between the laminar and turbulent regimes. The pressure ratio is the fraction of the outlet pressure over the inlet pressure.

**Dependencies**

This parameter is active when the **Laminar transition specification** parameter is set to **Pressure ratio**.

**Critical Reynolds number — Reynolds number at the laminar-turbulent flow transition**

12 (default) | unitless positive scalar

Maximum Reynolds number for laminar flow. This parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value, 12, corresponds to a round orifice in thin material with sharp edges.

**Dependencies**

This parameter is active when the **Laminar transition specification** parameter is set to **Reynolds number**.

## Version History

Introduced in R2006a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Gate Valve | Needle Valve | Poppet Valve | Pressure-Compensated Flow Control Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Ball Valve (IL)

Ball valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



### Description

The Ball Valve (IL) block represents a ball valve in an isothermal liquid network. A ball valve consists of a ball with a bore that can pivot inside of a valve body. When the valve is open, the bore fully overlaps with the valve body port. As the valve shuts, the ball rotates and reduces the amount of overlap, thereby reducing the effective area of the orifice. Ball valves are common for flow isolation purposes because they can securely shut off flow for many cycles. Ball valves are less common in applications where precise throttling is necessary.

You can parameterize the block analytically or by using tabulated data. When you set **Ball valve parameterization** to **Area of overlapping circles**, the block considers the area of the overlap between the valve port and the ball bore as the opening area such that

$$A_{open} = \sin(\varphi)R_{bore}^2[\cos^{-1}(\lambda_{bore}) - \lambda_{bore}\sqrt{1 - \lambda_{bore}^2}] + R_{port}^2[\cos^{-1}(\lambda_{port}) - \lambda_{port}\sqrt{1 - \lambda_{port}^2}]$$

$$\lambda_{bore} = \frac{R_{bore}^2 - R_{port}^2 + l^2}{2R_{bore}l}$$

$$\lambda_{port} = \frac{R_{port}^2 - R_{bore}^2 + l^2}{2R_{port}l}$$

where:

- $R_{port}$  and  $R_{bore}$  are the radii of the valve port and the ball bore, respectively.
- $l$  is the displacement of the bore center from the valve port center.
- $\varphi$  is the rotation of the ball valve given by the physical signal **S**. The valve is fully shut at 0 rad and fully open at  $\pi/2$  rad.

### Mass Flow Rate

The block calculates flow through the valve using the pressure-area relationship for orifices such that

$$\dot{m} = C_d A \sqrt{2\bar{\rho}} \frac{\Delta p}{(\Delta p^2 + \Delta p_{crit}^2)^{1/4}}$$

where:

- $C_d$  is the discharge coefficient.
- $\bar{\rho}$  is the average fluid density.

- $A$  is the area open to flow, where  $A = A_{open} + A_{leak}$ , and  $A_{leak}$  is the **Leakage area** parameter.
- $\Delta p_{crit}$  is the critical pressure differential associated with the critical Reynolds number,  $Re_{crit}$ .

The block calculates  $\Delta p_{crit}$  as

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8A} \left( \frac{v Re_{crit}}{C_d} \right)^2.$$

When you set **Flow coefficient parameterization** to Cd coefficient and area, you can specify  $C_d$  using the **Discharge coefficient (Cd)** parameter. When you set **Flow coefficient parameterization** to Cv coefficient (USCS), the block calculates  $C_d$  as

$$C_d = \frac{C_v}{A} \sqrt{\frac{\rho_{water, 60^\circ F}}{2\Delta p_{C_v}}},$$

where  $C_v$  is the **Maximum valve flow coefficient (Cv)** parameter. When you set **Flow coefficient parameterization** to Kv coefficient (SI), the block uses

$$C_d = \frac{K_v}{A} \sqrt{\frac{\rho_{water, 15^\circ C}}{2\Delta p_{K_v}}},$$

where  $K_v$  is the **Maximum valve flow factor (Kv)** parameter. In either equation,  $\Delta p_{C_v}$  is 1 psi and  $\Delta p_{K_v}$  is 1 bar.

## Ports

### Input

#### S – Valve position, rad

physical signal

Physical signal port associated with the position of the valve, in rad. A value of 0 represents a fully shut valve and a value of  $\pi/2$  represents a fully open valve.

### Conserving

#### A – Valve port A

isothermal liquid

Isothermal liquid conserving port associated with valve port A.

#### B – Valve port B

isothermal liquid

Isothermal liquid conserving port associated with valve port B.

## Parameters

### Ball valve parameterization – Ball valve parameterization

Area of overlapping circles (default) | Tabulated data

Option to parameterize the block using the method of area of overlapping circles or to use tabulated data.

**Flow coefficient parameterization – Option to parameterize given flow coefficient**  
Kv coefficient (SI) (default) | Cv coefficient (USCS) | Cd coefficient and area

Whether to parameterize the flow using  $K_v$ ,  $C_v$ , or  $C_d$ . The block uses these coefficient definitions:

- $K_v$  is the flow capacity of water through the fully open valve at 15°C with a pressure drop of 1 bar, in m<sup>3</sup>/h.
- $C_v$  is the flow capacity of water through the fully open valve at 60°F with a pressure drop of 1 psi, in gpm.
- $C_d$  is the unitless discharge coefficient that defines the efficiency of the valve.

**Maximum valve flow coefficient (Cv) – Maximum valve flow coefficient**

32 gpm (default) | positive scalar

Maximum value of the valve flow coefficient. This value should correspond to the fully open position.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Area of overlapping circles and **Flow coefficient parameterization** to Cv coefficient (USCS).

**Maximum valve flow factor (Kv) – Maximum valve flow factor**

49 m<sup>3</sup>/hr (default) | positive scalar

Maximum value of the valve flow factor. This value should correspond to the fully open position.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Area of overlapping circles and **Flow coefficient parameterization** to Kv coefficient (SI).

**Discharge coefficient (Cd) – Discharge coefficient**

0.64 (default) | positive scalar

Discharge coefficient of the valve. This value is a correction factor that accounts for losses in the theoretical flow.

**Dependencies**

To enable this parameter, set **Flow coefficient parameterization** to Cd coefficient and area.

**Cross-sectional area at ports A and B – Valve port cross-sectional area**

$\pi * (25 \wedge 2) / 4$  mm<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve ports. The valve ports are the paths in the valve body where the flow meets the ball bore.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Area of overlapping circles.

**Ball bore area – Area of ball bore**

$\pi * (20 \wedge 2) / 4$  mm<sup>2</sup> (default) | positive scalar

Cross-sectional area of the bore in the valve ball.



**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Area of overlapping circles.

**Valve flow coefficient (Cv) vector – Flow coefficient for given ball rotation**

[1e-06, .58, 1.15, 1.9, 2.8, 4.3, 7, 10.5, 17, 26, 32] gpm (default) | vector

Valve flow coefficient for a given ball rotation. Each element corresponds one-to-one with the **Ball rotation vector** parameter. The first element corresponds to the valve leakage and must be nonzero.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Tabulated data and **Flow coefficient parameterization** to Cv coefficient (USCS).

**Valve flow factor (Kv) vector – Flow factor for given ball rotation**

[1e-06, .34, .76, 1.6, 2.45, 4.1, 5.75, 9.4, 13, 28, 50] m<sup>3</sup>/hr (default) | vector

Valve flow factor for a given ball rotation. Each element corresponds one-to-one with the **Ball rotation vector** parameter. The first element corresponds to the valve leakage and must be nonzero.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Tabulated data and **Flow coefficient parameterization** to Kv coefficient (SI).

**Area vector – Area for given ball rotation**

[1e-10, 62.5, 125, 187.5, 250, 312.5, 375, 437.5, 500, 562.5, 625] mm<sup>2</sup> (default) | vector

Flow area for a given ball rotation. Each element corresponds one-to-one with the **Ball rotation vector** parameter. The first element corresponds to the valve leakage and must be nonzero.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Tabulated data and **Flow coefficient parameterization** to Cd coefficient and area.

**Ball rotation vector – Ball rotation**

$\pi / 2 .* [0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1]$  rad (default) | vector

Ball rotation for a given flow coefficient or area. The elements in this vector must align one-to-one with the elements in either the **Valve flow coefficient (Cv) vector** parameter, the **Valve flow factor (Kv) vector** parameter, or the **Area vector** parameter.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Tabulated data.

**Leakage area – Valve gap area when in fully shut position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully shut position. The block saturates any area smaller than this value to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Ball valve parameterization** to Area of overlapping circles.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Version History**

**Introduced in R2022b**

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Gate Valve (IL) | Check Valve (IL) | Variable Overlapping Orifice (IL)

# Poppet Valve (G)

Poppet valve in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Flow Control Valves



## Description

The Poppet Valve (G) block represents an orifice with a translating ball that moderates flow through the valve. In the fully closed position, the ball rests at the perforated seat, and fully blocks the fluid from passing between ports **A** and **B**. The area between the ball and seat is the opening area of the valve.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

### Ball Mechanics

The block models the displacement of the ball but not the valve opening or closing dynamics. The signal at port **L** provides the normalized ball position,  $L$ . Note that  $L$  is a normalized distance between 0 and 1, which indicate a fully closed valve and a fully open valve, respectively. If the calculation returns a number outside of this range, that number is set to the nearest bound.

### Numerical Smoothing

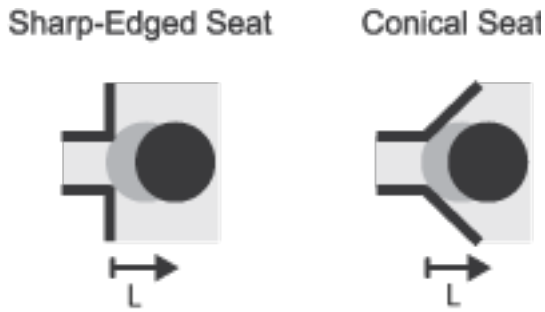
When the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized ball position,  $L$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Opening Area

The opening area of the valve depends on the **Valve seat geometry** parameter, which can be either Sharp-edged or Conical. The **Leakage flow fraction** parameter is the ratio of the flow rate of the valve when it is closed to when it is open. The **Leakage flow fraction** allows for small contact gaps between the ball and seat in the fully closed position. This parameter also maintains continuity in the flow for solver performance.

This figure shows the seat types for the poppet valve.



### Sharp-Edged Seat Geometry

The block calculates the opening area of the valve as

$$S_{open, sharp - edged} = \pi r_O \sqrt{(G_{sharp} + h)^2 + r_O^2} \left[ 1 - \frac{r_B^2}{(G_{sharp} + h)^2 + r_O^2} \right],$$

where:

- $h$  is the distance between the outer edge of the cylinder and the seat.
- $r_O$  is the seat orifice radius, which the block calculates from the **Orifice diameter** parameter.
- $r_B$  is the radius of the ball, which the block calculates from the **Ball diameter** parameter.
- $G_{sharp}$  is the geometric parameter:  $G_{sharp} = \sqrt{r_B^2 - r_O^2}$ .

The maximum displacement,  $h_{max}$ , bounds the opening area:

$$h_{max} = \sqrt{\frac{2r_B^2 - r_O^2 + r_O \sqrt{r_O^2 + 4r_B^2}}{2}} - G_{sharp}.$$

For any ball displacement larger than  $h_{max}$ ,  $S_{open}$  is the value of the maximum orifice area:

$$S_{open} = \frac{\pi}{4} d_O^2.$$

When the signal at port **L** is less than 0, the valve is closed and the **Leakage flow fraction** parameter determines the mass flow rate.

### Conical Seat Geometry

The block calculates the opening area of the valve as:

$$S_{open, conical} = G_{conical} h + \frac{\pi}{2} \sin(\theta) \sin\left(\frac{\theta}{2}\right) h^2,$$

where:

- $h$  is the vertical distance between the outer edge of the cylinder and the seat.
- $\theta$  is the value of the **Cone angle** parameter.
- $G_{conical}$  is the geometric parameter,  $G_{conical} = \pi r_B \sin(\theta)$ , where  $r_B$  is the ball radius.

The maximum displacement,  $h_{max}$ , bounds the opening area:

$$h_{\max} = \frac{\sqrt{r_B^2 + \frac{r_O^2}{\cos\left(\frac{\theta}{2}\right)} - r_B}}{\sin\left(\frac{\theta}{2}\right)}.$$

For any ball displacement larger than  $h_{\max}$ ,  $S_{open}$  is the value of the maximum orifice area:

$$S_{open} = \frac{\pi}{4}d_O^2.$$

When the signal at port **L** is less than 0, the valve is closed and the **Leakage flow fraction** parameter determines the mass flow rate.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area based on geometry** — The size of the flow restriction determines the block parametrization.

The block scales the specified flow capacity by the fraction of valve opening. As the fraction of valve opening rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.

### Mass Flow Rate

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v \frac{S_{open}}{S_{Max}} N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the value of the **Maximum Cv flow coefficient** parameter.
- $S_{open}$  is the valve opening area.
- $S_{Max}$  is the maximum valve area where the valve is fully open.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.

- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3p_{in}F_{\gamma}x_T},$$

where:

- $F_{\gamma}$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v \frac{S_{open}}{S_{Max}} N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{p_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3F_{\gamma}x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma}x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3} C_v \frac{S_{open}}{S_{Max}} N_6 \sqrt{F_{\gamma}x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{\frac{p_{out}}{p_{in}} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m,$$

where:

- $C$  is the value of the **Maximum sonic conductance** parameter.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.

- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ .

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} \sqrt{\frac{T_{ref}}{T_{avg}}} \left[ 1 - \left( \frac{B_{lam} - B_{crit}}{1 - B_{crit}} \right)^{2m} \right] \left( \frac{p_{in} - p_{out}}{1 - B_{lam}} \right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area based on geometry, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}} \frac{1 - \left( \frac{p_{out}}{p_{in}} \right)^{\frac{\gamma-1}{\gamma}}}{1 - \left( \frac{S_{open}}{S} \right)^2 \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}}}},$$

where:

- $S_{open}$  is the valve opening area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ .

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left( \frac{S_{open}}{S} \right)^2 B_{lam}^{\frac{2}{\gamma}}} \left( \frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}} \right)}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left( \frac{2}{\gamma+1} \right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left( \frac{\gamma+1}{2} \right)^{\frac{2}{\gamma-1}} - \left( \frac{S_{open}}{S} \right)^2}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area based on geometry, see [4].

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Assumptions and Limitations

- The **Sonic conductance** setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice area based on geometry** parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Conserving

#### **A — Liquid port**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

#### **B — Liquid port**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve.

### Input

#### **L — Normalized ball displacement, in the range of [0,1]**

physical signal



Normalized ball displacement. The ball position is normalized by the maximum opening distance. A value of 0 indicates a fully closed valve and a value of 1 indicates a fully open valve.

## Parameters

### Valve seat specification — Definition of valve seat geometry

Sharp-edged (default) | Conical

Geometry of the seat of the ball. This parameter determines the opening area of the valve.

### Cone angle — Angle between the conical seat of the valve and its center lines

120 deg (default) | positive scalar

Angle formed by the slope of the conical seat against its center line.

#### Dependencies

To enable this parameter, set **Valve seat specification** to Conical.

### Ball diameter — Diameter of the ball used to regulate valve opening

0.01 m (default) | scalar

Diameter of the ball control element.

### Orifice diameter — Diameter of the valve orifice

7e-3 m (default) | scalar

Diameter of the valve constant orifice. For a conical geometry, the diameter the root of the seat.

### Valve parameterization — Parameterization used to specify flow characteristics of orifice

Orifice area based on geometry (default) | Cv flow coefficient | Kv flow coefficient | Sonic conductance

Method to calculate the mass flow rate.

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization.
- **Orifice area based on geometry** — The size of the flow restriction determines the block parameterization.

### Discharge coefficient — Discharge coefficient

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Orifice area based on geometry.

### Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient.

**xT pressure differential ratio factor at choked flow – Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Maximum Kv flow coefficient – Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Maximum value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient.

**Maximum sonic conductance – Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Critical pressure ratio – Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Subsonic index – Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**ISO reference temperature – ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**ISO reference density – ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**Leakage flow fraction – Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B – Flow area at gas ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

**Introduced in R2018b****Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction**. This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

### **Updated block name**

The title of the Ball Valve (G) block changed to Poppet Valve (G).

### **Offset parameter removed**

The block no longer has a **Valve lift control offset** parameter and the block no longer offsets the input signal. This change does not impact compatibility.

## **References**

- [1] ISO 6358-3. "Pneumatic fluid power - Determination of flow-rate characteristics of components using compressible fluids - Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves - Part 2-3: Flow capacity - Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves - Part 2-1: Flow capacity - Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg, 2007.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Orifice (G) | Gate Valve (G)

# Cartridge Valve Insert

Hydraulic cartridge valve insert

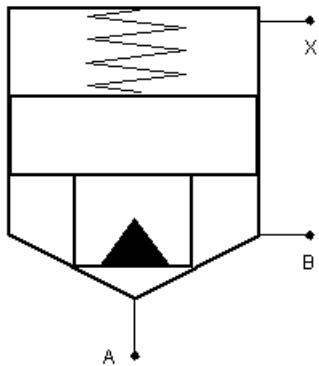


## Library

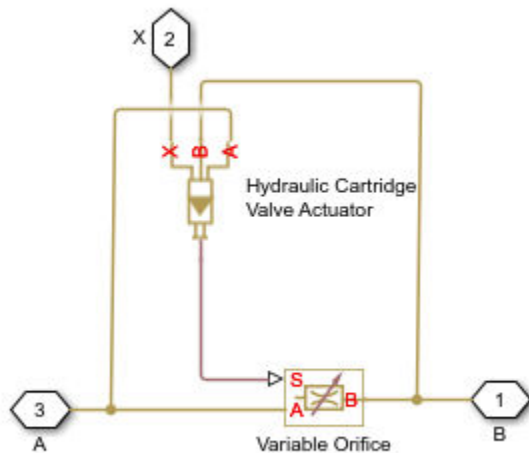
Directional Valves

## Description

The Cartridge Valve Insert block represents an insert of a hydraulic cartridge valve consisting of a poppet interacting with the seat. The poppet position is determined by pressures at ports A, B, and X and force of the spring. A schematic diagram of the cartridge valve insert is shown in the following illustration.



The Cartridge Valve Insert block is a structural model consisting of a Hydraulic Cartridge Valve Actuator block and a Variable Orifice block, as shown in the next illustration.



Pressures at port A and port B tend to open the valve, while pressure at the control port X, together with the spring, acts to close it. The model does not account for flow rates caused by poppet displacement and any loading on the poppet, such as inertia and friction. The valve remains closed as long as the aggregate pressure force is lower than the spring preload force. The poppet is forced off its seat as the preload force is reached and moves up proportionally to pressure increase until it passes the full stroke. Hydraulic properties of the gap between the poppet and the seat are simulated with the Variable Orifice block.

Connections A, B, and X are hydraulic conserving ports associated with the valve inlet, valve outlet, and valve control terminal, respectively. The block positive direction is from port A to port B. Pressure at port X acts to close the valve, while pressures at port A and port B act to open the orifice.

## Basic Assumptions and Limitations

- Valve opening is linearly proportional to the pressure differential.
- No loading on the poppet, such as inertia or friction, is considered.
- The model does not account for flow rates caused by poppet displacement.
- For orifices specified by the passage area (the first two parameterization options), the transition between laminar and turbulent regimes is assumed to be sharp and taking place exactly at  $Re=Re_{cr}$ .
- For orifices specified by pressure-flow characteristics (the third parameterization option), the model does not explicitly account for the flow regime or leakage flow rate because the tabulated data is assumed to account for these characteristics.

## Parameters

### Port A poppet area

Effective poppet area at port A. The parameter value must be greater than zero. The default value is  $2e-4 \text{ m}^2$ .

### Port A to port X area ratio

Ratio between poppet areas at port A and port X. The parameter value must be greater than zero. The default value is 0.66.

**Preload force**

Spring preload force. The default value is 26 N.

**Spring rate**

Spring rate. The default value is 1.4e4 N/m.

**Poppet stroke**

Maximum poppet stroke. The parameter value must be greater than or equal to zero. The default value is 5e-3 m. This parameter is used if **Orifice specification** is set to **By maximum area and opening**.

**Initial opening**

The initial opening of the valve. Its value must be greater than or equal to zero. The default value is 0.

**Orifice specification**

Select one of the following methods for specifying the hydraulic properties of the gap between the poppet and the seat:

- **By maximum area and opening** — Provide values for the maximum orifice area and the maximum orifice opening. The passage area is linearly dependent on the control member displacement, that is, the orifice is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of orifice openings and corresponding orifice areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of orifice openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

For more information on these options, see the Variable Orifice block reference page.

**Orifice maximum area**

Specify the area of a fully opened orifice. The parameter value must be greater than zero. The default value is 5e-5 m<sup>2</sup>. This parameter is used if **Orifice specification** is set to **By maximum area and opening**.

**Tabulated orifice openings**

Specify the vector of input values for orifice openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are [-0.002 0 0.002 0.005 0.015]. If **Orifice specification** is set to **By area vs. opening table**, the **Tabulated orifice openings** values will be used together with **Tabulated orifice area** values for one-dimensional table lookup. If **Orifice specification** is set to **By pressure-flow characteristic**, the **Tabulated orifice openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

**Tabulated orifice area**

Specify the vector of orifice areas as a one-dimensional array. The vector must be of the same size as the orifice openings vector. All the values must be positive. The default values, in m<sup>2</sup>, are



[1e-09 2.0352e-07 4.0736e-05 0.00011438 0.00034356]. This parameter is used if **Orifice specification** is set to By area vs. opening table.

### Tabulated pressure differentials

Specify the pressure differential vector as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are [-1e+07 -5e+06 -2e+06 2e+06 5e+06 1e+07]. This parameter is used if **Orifice specification** is set to By pressure-flow characteristic.

### Tabulated flow rates

Specify the flow rates as an m-by-n matrix, where m is the number of orifice openings and n is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of orifice opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in m<sup>3</sup>/s, are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Orifice specification** is set to By pressure-flow characteristic.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (By area vs. opening table) or surface (By pressure-flow characteristic) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### **Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### **Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### **Time constant**

Sets the time constant of the first-order lag, which is introduced between the required and the actual poppet positions to account for actuator dynamics. The parameter value must be greater than zero. The default value is 0.01 s.

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Orifice specification**
- **Interpolation method**
- **Extrapolation method**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Orifice specification** parameter at the time the model entered Restricted mode.

### **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

X

Hydraulic conserving port associated with the valve control terminal.

## Version History

Introduced in R2008a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Cartridge Valve Insert with Conical Seat | Check Valve | Hydraulic Cartridge Valve Actuator | Pilot-Operated Check Valve

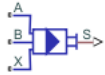
## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Cartridge Valve Actuator (IL)

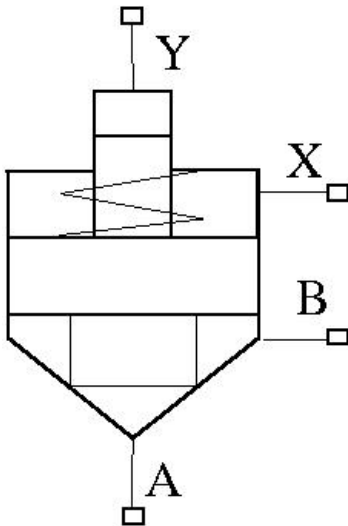
Actuator that maintains equilibrium between valve and pilot pressures in an isothermal liquid system

**Library:** Simscape / Fluids / Valve Actuators & Forces



### Description

The Cartridge Valve Actuator (IL) block models an actuator that maintains equilibrium between the valve and pilot-line pressures. The valve between ports **A** and **B** remains closed until the pilot spring **Spring preload force** is surpassed, at which point the piston begins to move. The piston position is output as a physical signal at port **S**. A schematic of a 4-port cartridge valve actuator is shown below.



### Actuator Force Balance

The actuator piston moves to adjust the pressure in the actuator chamber, which maintains equilibrium between the actuator port pressures and pilot line pressures:

$$p_A A_A + p_B A_B = F_{preload} + F_{pilot},$$

where:

- $p_A$  and  $p_B$  are the pressures at ports **A** and **B**.
- $A_X$  is calculated from the **Port A to port X area ratio**.
- $A_B$  is the port **B** area,  $A_X - A_A$ , when the **Number of pressure ports** is set to 3. When the **Number of pressure ports** is set to 4,  $A_B$  is  $A_X - A_A + A_Y$ .
- $F_{preload}$  is the initial spring force in the system.
- $F_{pilot}$  is  $p_X A_X$  if **Number of pressure ports** is set to 3 and  $p_X A_X + p_Y A_Y$  if **Number of pressure ports** is set to 4.

## Piston Position

The steady piston displacement is calculated as:

$$x_{steady} = \frac{F\varepsilon}{k} = \frac{F_A + F_B - F_{pilot} - F_{preload}}{k} \varepsilon,$$

where  $\varepsilon$  is the **Opening orientation**, which assigns movement in a positive direction (extension) or negative direction (retraction). The dynamic change in piston displacement is:

$$\dot{x}_{dyn} = \frac{x_{steady} - x_{dyn}}{\tau},$$

where  $\tau$  is the **Actuator time constant**. When  $\dot{x}_{dyn} = \frac{x_{dyn}}{\tau}$  is less than the **Spring preload force**,  $x_{steady} = 0$ .

If  $\dot{x}_{dyn} = \frac{x_{dyn}}{\tau}$  is greater than the sum of the preload force and  $kx_{stroke}$ ,  $x_{steady} = x_{stroke}$ .

## Opening Dynamics

If opening dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{control}$  becomes the dynamic control pressure,  $p_{dyn}$ ; otherwise,  $p_{control}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, **Opening dynamics** is set to Off.

## Numerically-Smoothed Force

When the actuator is close to full extension or full retraction, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to all calculated forces, but primarily influences the simulation at the extremes of the piston motion.

The normalized force is

$$\hat{F} = \frac{F_A + F_B - F_{Preload} - F_{Pilot}}{kx_{stroke}}.$$

where:

- $F_A$  is the force at port **A**.
- $F_B$  is the force at port **B**.
- $F_{Preload}$  is the **Spring preload force**.
- $F_{Pilot}$  is the force at port **X**.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the normalized force between 0 and 1.

For more information, see “Numerical Smoothing”.

## Assumptions and Limitations

Internal fluid volumes are not modeled in this block. There is no mass flow rate through ports **A**, **B**, **X**, and **Y**.

## Ports

### Conserving

#### **A — Pressure port**

isothermal liquid

Pressure port associated with the valve inlet.

#### **B — Pressure port**

isothermal liquid

Pressure port associated with the valve outlet.

#### **X — Pressure port**

isothermal liquid

Pressure port at poppet end.

#### **Y — Pressure port**

isothermal liquid

Pilot pressure port. To enable this port, set **Number of pressure ports** to 4.

## Output

#### **S — Poppet position, m**

physical signal

Poppet position in m, specified as a physical signal.

## Parameters

#### **Number of pressure ports — Number of pilot pressure ports**

3 (default) | 4

Number of pilot pressure ports. Port **X** measures the pressure at the end of the poppet. Setting this parameter to 4 enables the additional pilot-side port **Y**.

#### **Port A poppet area — Cross-sectional area of port A**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of port **A**.

#### **Port A poppet to port X pilot area ratio — Ratio of inlet to pilot port area**

0.5 (default) | positive scalar

Ratio of the inlet port, **A**, to the pilot pressure port, **X**. This value is used to calculate the force at port **X**.

**Port Y pilot area – Cross-sectional area of port Y**1.5e-4 m<sup>2</sup> (default) | positive scalarCross-sectional area of port **Y**.**Dependencies**To enable this parameter, set **Number of pressure ports** to 4.**Spring preload force – Initial spring force**

25 N (default) | positive scalar

Spring force in the valve due to spring preloading. This parameter is a threshold value which, when added to the pilot pressures at ports **X** and **Y**, counterbalances the valve opening due to the pressures at ports **A** and **B**.

**Spring stiffness – Stiffness constant**

15e3 N/m (default) | positive scalar

Spring stiffness constant.

**Poppet stroke – Maximum poppet extension**

5e-3 m (default) | positive scalar

Maximum poppet extension.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the piston position when it is near full extension or full retraction. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Connected valve opening orientation – Direction of poppet displacement**

Positive displacement opens valve (default) | Negative displacement opens valve

Direction of the poppet displacement that opens a connected valve. Setting this parameter to **Positive displacement opens valve** indicates poppet extension. Setting the parameter to **Negative displacement opens valve** indicates poppet retraction.

**Actuator dynamics – Whether to account for transients during actuation**

Off (default) | On

Whether to account for transient effects in the spool position due to actuation. Setting **Actuator dynamics** to **On** approximates actuator motion by introducing a first-order lag in the spool position. The **Actuator time constant** also impacts the modeled dynamics.

**Actuator time constant – Piston displacement time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the piston to reach steady-state when moving from one position to another. This parameter impacts the modeled actuator dynamics.

**Dependencies**To enable this parameter, set **Actuator dynamics** to **On**.

## **Version History**

**Introduced in R2020a**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

#### **See Also**

Cartridge Valve Insert (IL) | Pilot Valve Actuator (IL) | Pilot-Operated Check Valve (IL) | Shuttle Valve (IL) | 3-Way Directional Valve (IL)



# Cartridge Valve Insert (IL)

Cartridge flow-control valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



## Description

The Cartridge Valve Insert (IL) block models a cartridge flow-control valve in an isothermal liquid network. The valve seat can be specified as conical or as a custom opening parameterized by analytical or tabular formulations. The valve opens when the combined pressures at ports **A** and **B** exceed the **Spring preload force** and pressure at port **X**.

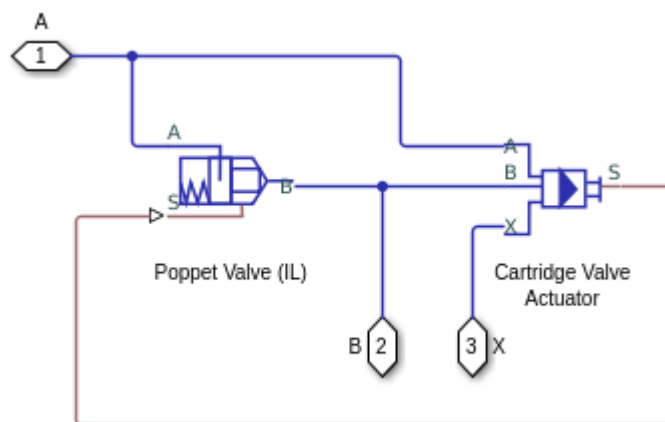
You can specify the block seat geometry as either conical or a custom. This seat setting determines the sub-components that make up the block. In both configurations, the **Port A poppet to port X pilot area ratio** parameter sets the force ratio in the underlying Cartridge Valve Actuator block.

Use the Cartridge Valve Insert (IL) block when you would like flow control set by a pilot pressure line. Use the Pressure-Compensated 3-Way Flow Control Valve (IL) or Pressure-Compensated Flow Control Valve (IL) block for flow control due to a pressure differential or the Poppet Valve (IL) block for valve opening controlled by an external physical signal.

### Conical Valve Seat

The conical cartridge valve insert is a composite of two Isothermal Liquid library blocks:

- Poppet Valve (IL)
- Cartridge Valve Actuator (IL)

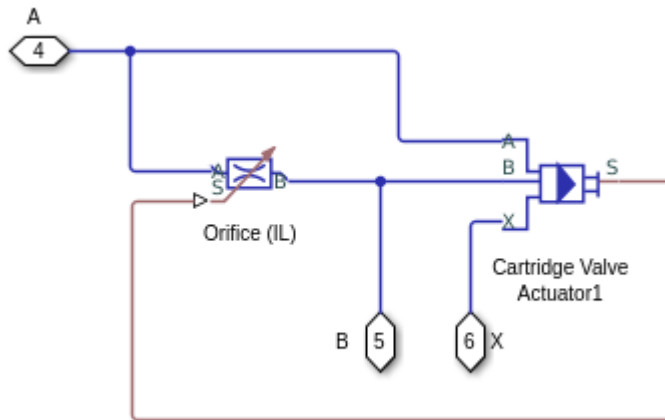


**Conical Cartridge Valve Insert Schematic**

## Custom Valve Seat

The custom cartridge valve insert is a composite of two Isothermal Liquid library blocks:

- Orifice (IL)
- Cartridge Valve Actuator (IL)



In the custom configuration, you can parameterize the valve opening analytically or with a data set.

## Custom Cartridge Valve Insert Schematic

### Analytical Parameterization

By setting **Orifice parameterization** to Linear - area vs. control member position, the valve opening area is linearly proportional to the poppet position. Once the pressure at port **A** or **B** exceeds the **Spring preload force**, the valve opens until the **Maximum orifice area** is reached. When the valve is fully closed, a small **Leakage area** remains open to flow so that numerical continuity is maintained in the network.

### Tabulated Parameterization

By setting **Orifice parameterization** to Tabulated data - Area vs. control member position, you can supply the opening profile based on opening area and poppet position. The block queries between data points with linear interpolation and uses nearest extrapolation for points beyond the table boundaries.

By setting **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop, you can supply the volumetric flow rate through the valve as a parameterized table of poppet position and valve pressure drop. The block queries between data points with linear interpolation and uses linear extrapolation for points beyond the table boundaries. The volumetric flow rate is converted to a mass flow rate by multiplying by the fluid density.

### Opening Dynamics

If opening dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{\text{control}}$  becomes the dynamic control pressure,  $p_{\text{dyn}}$ ; otherwise,  $p_{\text{control}}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, **Opening dynamics** is set to Off.

### Numerically-Smoothed Force and Opening

When the actuator is close to full extension or full retraction, and **Orifice parameterization** is set to **Linear - area vs. control member position**, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to the actuator force and orifice opening or area, but primarily influences the simulation at the extremes of these ranges.

The normalized force that opens the valve is

$$\hat{F} = \frac{F_A + F_B - F_{Preload} - F_{Pilot}}{k \times stroke}.$$

where:

- $F_A$  is the force at port **A**.
- $F_B$  is the force at port **B**.
- $F_{Preload}$  is the **Spring preload force**.
- $F_{Pilot}$  is the force at port **X**.

When **Valve seat specification** is set to **Conical**, the block smoothly saturates the orifice opening distance between  $\theta$  and the maximum orifice opening distance. When **Valve seat specification** is set to **Custom**, the block smoothly saturates the valve opening area between the **Leakage area** parameter and the **Maximum orifice area** parameter.

For more information, see “Numerical Smoothing”.

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry or exit port.

#### B — Liquid port

isothermal liquid

Liquid entry or exit port.

#### X — Pressure port

isothermal liquid

Pilot pressure port. There is no mass flow rate through port **X**.

## Parameters

### Valve seat specification — Geometry of valve seat

Conical (default) | Custom

Geometry of valve seat. This parameter is used for calculating the open area between the poppet and seat.

### Poppet diameter — Diameter of the valve control member

0.01 m (default) | positive scalar

Diameter of the valve control member.

#### Dependencies

To enable this parameter, set **Valve seat specification** to Conical.

### Seat cone angle — Angle of the seat opening

120 deg (default) | positive scalar

Angle of the seat opening.

#### Dependencies

To enable this parameter, set **Valve seat specification** to Conical.

### Orifice parameterization — Method of calculating orifice area

Linear - area vs. control member position (default) | Tabulated data - Area vs. control member position | Tabulated data - Volumetric flow rate vs. control member position and pressure drop

The valve opening is calculated in one of three ways, linearly or by tabulated data:

- **Linear - area vs. control member position:** The orifice area is determined by a linear relationship to the poppet opening or closing distance.
- **Tabulated data - Area vs. control member position:** The opening area is interpolated from the **Poppet position vector** and the **Orifice area vector** based on the current poppet position.
- **Tabulated data - Volumetric flow rate vs. control member position and pressure drop.** The volumetric flow rate is directly interpolated from the provided **Poppet position vector,  $s$** ; **Pressure drop vector,  $dp$** ; and **Volumetric flow rate table,  $q(s,dp)$**  parameters, based on the current poppet position.

#### Dependencies

To enable this parameter, set **Valve seat specification** to Custom.

### Poppet stroke — Maximum poppet extension

5e-3 m (default) | positive scalar

Maximum poppet extension.

#### Dependencies

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Linear - area vs. control member position.

**Maximum orifice area — Maximum orifice cross-sectional area**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice in its fully open position. This parameter is used as an upper limit for area-pressure calculations during the simulation.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Linear - area vs. control member position.

**Poppet position vector — Vector of opening positions**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of orifice opening positions for the tabular parameterization of the orifice opening area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Orifice area vector — Vector of opening areas**

[ $1e-09$ ,  $2.0352e-07$ ,  $4.0736e-05$ , .00011438, .00034356]  $\text{m}^2$  (default) | 1-by-*n* vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Poppet position vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Poppet position vector, *s* — Vector of control member positions**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member positions for the tabular parameterization of the volumetric flow rate. The spool travel vector forms an independent axis with the **Pressure drop vector, *dp*** parameter for the 3-D dependent **Volumetric flow rate table, *q(s,dp)*** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Pressure drop vector, *dp* — Vector of pressure differential values**

[.3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Poppet position vector, *s*** parameter for the 3-D dependent **Volumetric flow rate table, *q(s,dp)*** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Volumetric flow rate table,  $q(s, dp)$  — Array of volumetric flow rate values**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  array

Matrix of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Poppet position vector,  $s$**  parameter.
- $N$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.

**Dependencies**

To enable this parameter, set **Valve seat specification** to Custom and **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Port A poppet area — Cross-sectional area of port A**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of port **A**.

**Port A poppet to port X pilot area ratio — Ratio of inlet to pilot port area**

0.5 (default) | positive scalar

Ratio of the inlet port, **A**, to the pilot pressure port, **X**. This value is used to calculate the force at port **X**. The ratio must be less than or equal to 1.

**Spring preload force — Spring force in neutral poppet position**

25 N (default) | positive scalar

Spring force on the poppet when the poppet is in the neutral position. This parameter is a threshold value which, when added to the pilot pressure at port **X**, counterbalances the valve opening due to the pressures at ports **A** and **B**.

**Spring stiffness — Stiffness constant**

15e3 N/m (default) | positive scalar

Spring stiffness constant.

**Leakage area — Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set either:

- **Valve seat specification** to Conical.

- **Valve seat specification** to Custom and **Orifice parameterization** to Linear - Area vs. control member position.

### **Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

#### **Dependencies**

To enable this parameter, set either:

- **Valve seat specification** to Conical.
- **Valve seat specification** to Custom and **Orifice parameterization** to Linear - Area vs. control member position or Tabulated data - Area vs. control member position.

### **Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

#### **Dependencies**

To enable this parameter, set either:

- **Valve seat specification** to Conical.
- **Valve seat specification** to Custom and **Orifice parameterization** to Linear - Area vs. control member position or Tabulated data - Area vs. control member position.

### **Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

#### **Dependencies**

To enable this parameter, set either:

- **Valve seat specification** to Conical.
- **Valve seat specification** to Custom and **Orifice parameterization** to Linear - Area vs. control member position.

### **Valve opening time constant – Valve time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state conditions when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Cartridge Valve Actuator (IL) | Poppet Valve (IL) | Orifice (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure-Compensated Flow Control Valve (IL)



# Cartridge Valve Insert with Conical Seat

Hydraulic cartridge valve insert with conical seat

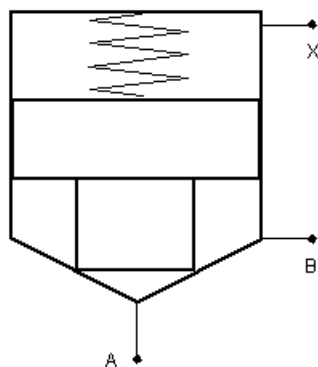


## Library

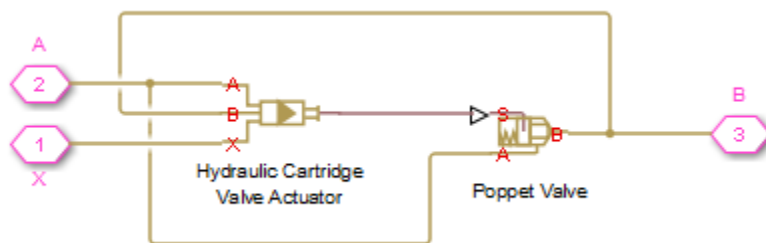
Directional Valves

## Description

The Cartridge Valve Insert with Conical Seat block represents an insert of a hydraulic cartridge valve consisting of a poppet interacting with the conical seat. The poppet position is determined by pressures at ports A, B, and X and force of the spring. A schematic diagram of the cartridge valve insert with conical seat is shown in the following illustration.



The Cartridge Valve Insert with Conical Seat block is a structural model consisting of a Hydraulic Cartridge Valve Actuator block and a Poppet Valve block, as shown in the next illustration.



Pressures at port A and port B tend to open the valve, while pressure at the control port X, together with the spring, acts to close it. The model does not account for flow rates caused by poppet

displacement and any loading on the poppet, such as inertia and friction. The valve remains closed as long as the aggregate pressure force is lower than the spring preload force. The poppet is forced off its seat as the preload force is reached and moves up proportionally to pressure increase until it passes the full stroke. Hydraulic properties of the gap between the poppet and the seat are simulated with the Poppet Valve block.

Connections A, B, and X are hydraulic conserving ports associated with the valve inlet, valve outlet, and valve control terminal, respectively. The block positive direction is from port A to port B. Pressure at port X acts to close the valve, while pressures at port A and port B act to open the orifice.

## Basic Assumptions and Limitations

- Valve opening is linearly proportional to the pressure differential.
- No loading on the poppet, such as inertia or friction, is considered.
- The model does not account for flow consumption caused by poppet displacement.

## Parameters

### Port A poppet area

Effective poppet area at port A. The parameter value must be greater than zero. The default value is  $2e-4 \text{ m}^2$ .

### Port A to port X area ratio

Ratio between poppet areas at port A and port X. The parameter value must be greater than zero. The default value is 0.66.

### Preload force

Spring preload force. The default value is 26 N.

### Spring rate

Spring rate. The default value is  $1.4e4 \text{ N/m}$ .

### Poppet stroke

Maximum poppet stroke. The parameter value must be greater than zero. The default value is 0.005 m.

### Poppet diameter

Maximum poppet diameter. The parameter value must be greater than or equal to zero. The default value is 0.01 m.

### Seat cone angle

The cone angle of the valve seat. The default value is 120 degrees.

### Initial opening

The initial opening of the valve. Its value must be greater than or equal to zero. The default value is 0.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### Time constant

Sets the time constant of the first-order lag, which is introduced between the required and the actual poppet positions to account for actuator dynamics. The parameter value must be greater than zero. The default value is 0.01 s.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

X

Hydraulic conserving port associated with the valve control terminal.

## **Examples**

For an example of using this block, see the “Injection Molding Actuation System” example.

## **Version History**

**Introduced in R2010a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

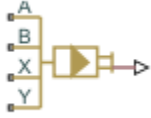
Cartridge Valve Insert | Hydraulic Cartridge Valve Actuator | Poppet Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Hydraulic 4-Port Cartridge Valve Actuator

Double-acting hydraulic valve actuator driven by four pressures

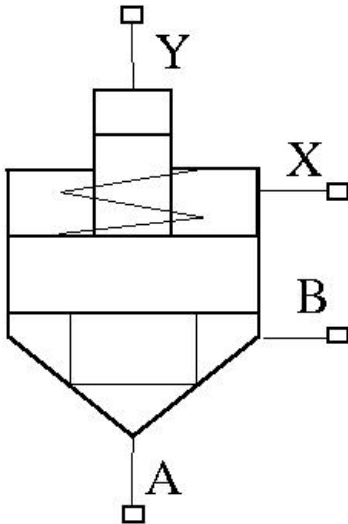


## Library

Valve Actuators

## Description

The Hydraulic 4-Port Cartridge Valve Actuator block represents a double-acting hydraulic valve actuator driven by four pressures. Use it as a pilot actuator for cartridge valves, pilot-operated pressure and control valves, and similar devices. A schematic diagram of the 4-port cartridge valve actuator is shown in the following illustration.



The actuator drives a valve (spool, poppet, and so on) whose position depends on pressures at ports A, B, X, and Y and the spring force. Pressures at ports A and B tend to open the valve, while pressures at control ports X and Y, together with the spring force, act to close it. The model does not account for flow consumption and loading forces, except spring and pressure forces.

Inertial properties of the actuator are accounted for by adding a first order lag between the steady-state and actual valve displacements. The lag is simulated with the combination of the PS Gain and PS Integrator blocks, enveloped by the unity feedback.

The valve remains closed as long as the aggregate pressure force is lower than the spring preload force. The poppet is forced off its seat as the preload force is reached and moves up proportionally to pressure increase until it passes the full stroke.

The force acting on the poppet and the poppet displacement are computed with the following equations:

$$F_P = p_A \cdot A_A + p_B \cdot A_B - p_X \cdot A_X - p_Y \cdot A_Y$$

$$x_S = \begin{cases} 0 & \text{for } F_P \leq F_{PR} \\ (F_P - F_{PR})/k_{spr} & \text{for } F_{PR} < F_P < F_{PR} + k_{spr} \cdot x_{max} \\ x_{max} & \text{for } F_P \geq F_{PR} + k_{spr} \cdot x_{max} \end{cases}$$

$$x = x_S \frac{1}{T_S + 1}$$

where

$F_P$	Pressure force acting on the poppet
$p_A, p_B, p_X, p_Y$	Pressures at ports A, B, X, and Y, respectively
$A_A, A_B, A_X, A_Y$	Areas at ports A, B, X, and Y, respectively. Areas at ports A and Y are block parameters. Area at port X is specified by its ratio to that at port A, $A_A / A_X$ . Area at port B is determined as $A_B = A_X - A_A$ .
$x$	Actual poppet displacement
$x_S$	Steady-state poppet displacement
$x_{max}$	Full stroke
$F_{PR}$	Spring preload force
$k_{spr}$	Spring rate

Connections A, B, X, and Y are hydraulic conserving ports associated with the actuator ports. Connection P is a physical signal port whose output corresponds to poppet displacement. Pressures applied at ports A and B move the poppet in the positive or negative direction, depending on the value of the **Actuator orientation** parameter. Pressures at ports X and Y act in the opposite direction to pressures at ports A and B.

## Basic Assumptions and Limitations

- The flow consumption associated with the valve motion is assumed to be negligible.
- The inertia, friction, and hydraulic axial forces are assumed to be small and are not taken into account.

## Parameters

### Port A poppet area

Effective poppet area at port A. The parameter value must be greater than zero. The default value is  $3.3e-4 \text{ m}^2$ .

### Port A to port X area ratio

Ratio between poppet areas at port A and port X. The parameter value must be greater than zero. The default value is  $0.66$ .

**Port Y piston area**

Effective piston area at port Y. The parameter value must be greater than zero. The default value is  $1.65e-4 \text{ m}^2$ .

**Preload force**

Spring preload force. The default value is 26 N.

**Spring rate**

Spring rate. The default value is  $1.4e4 \text{ N/m}$ .

**Poppet stroke**

Maximum poppet stroke. The parameter value must be greater than zero. The default value is  $5e-3 \text{ m}$ .

**Poppet-seat initial gap**

Initial gap between the poppet and the seat. The parameter value must be greater than or equal to zero. The default value is 0.

**Time constant**

Time constant of the first-order lag. The default value is 0.01 s.

**Actuator orientation**

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it moves the poppet in the positive or in the negative direction when pressure is applied at its inlet. If pressures applied at ports A and B move the poppet in the negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

X

Hydraulic conserving port associated with the valve control terminal.

Y

Hydraulic conserving port associated with the valve control terminal.

P

Physical signal port that outputs poppet displacement.

## **Examples**

For an example of using this block, see the “Injection Molding Actuation System” example.

## **Version History**

**Introduced in R2010a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Hydraulic Cartridge Valve Actuator



# Hydraulic Cartridge Valve Actuator

Double-acting hydraulic actuator for cartridge valves



## Library

Valve Actuators

## Description

Use the Hydraulic Cartridge Valve Actuator block as a pilot actuator for cartridge valves, as well as pilot-operated pressure and control valves in applications where all the forces, except spring and pressure forces, and flow consumption can be neglected. This block represents a double-acting hydraulic valve actuator driven by three pressures. The actuator drives a valve (spool, poppet, etc.) whose position depends on pressures at ports A, B, and X and the force of the spring. Pressures at ports A and B tend to open the valve, while pressure at control port X together with the spring force act to close it.

Inertial properties of the actuator are accounted for by adding a first order lag between the steady-state and actual valve displacements. The lag is simulated with the combination of the PS Gain and PS Integrator blocks, enveloped by the unity feedback.

The valve remains closed as long as the aggregate pressure force is lower than the spring preload force. The poppet is forced off its seat as the preload force is reached and moves up proportionally to pressure increase until it passes the full stroke.

Connections A, B, and X are hydraulic conserving ports associated with the actuator ports. Connection P is a physical signal port whose output corresponds to poppet displacement. Pressures applied at ports A and B move the poppet in the positive or negative direction, depending on the value of the **Actuator orientation** parameter, with pressure at port X acting in the opposite direction.

## Basic Assumptions and Limitations

- The flow consumption associated with the valve motion is assumed to be negligible.
- The inertia, friction, and hydraulic axial forces are assumed to be small and are not taken into account.
- The clearances between the valve and the washers are not taken into account.

## Parameters

### Port A poppet area

Effective poppet area at port A. The parameter value must be greater than zero. The default value is  $3.3e-4 \text{ m}^2$ .

**Port A to port X area ratio**

Ratio between poppet areas at port A and port X. The parameter value must be greater than zero. The default value is 0.66.

**Preload force**

Spring preload force. The default value is 26 N.

**Spring rate**

Spring rate. The default value is 1.4e4 N/m.

**Poppet stroke**

Maximum poppet stroke. The parameter value must be greater than or equal to zero. The default value is 5e-3 m.

**Poppet-seat initial gap**

Initial gap between the poppet and the seat. The parameter value must be greater than or equal to zero. The default value is 0.

**Time constant**

Time constant of the first-order lag. The default value is 0.01 s.

**Actuator orientation**

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it moves the poppet in the positive or in the negative direction when pressure is applied at its inlet. If pressures applied at ports A and B move the poppet in the negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

X

Hydraulic conserving port associated with the valve control terminal.

P

Physical signal port that outputs poppet displacement.

**Version History**

**Introduced in R2008a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

2-Position Valve Actuator | 3-Position Valve Actuator | Cartridge Valve Insert | Hydraulic Double-Acting Valve Actuator | Hydraulic Single-Acting Valve Actuator | Proportional and Servo-Valve Actuator

# Centrifugal Force in Rotating Cylinder

Centrifugal force in rotating hydraulic cylinders



## Library

Hydraulic Cylinders

## Description

The Centrifugal Force in Rotating Cylinder block is a building block to be used in hydraulic cylinder models, to account for centrifugal forces exerted by fluid on a piston, if the cylinder rotates about its symmetry axis. Such cylinders are used in control mechanisms of various friction clutches, brakes, square-jaw positive clutches, dog clutches, and so on. No inertial effects are considered in the model. In other words, the angular velocity is assumed to be constant or changing at very low speed.

The centrifugal force is computed with the following equation:

$$F = \frac{\pi\rho\omega^2}{4}(r_o^4 - r_i^4 - 2r_p^2(r_o^2 - r_i^2))$$

where

$F$	Centrifugal force
$r_o$	Piston outer radius
$r_i$	Piston inner radius
$r_p$	Fluid entry radius. For design purposes, $r_p < \sqrt{(r_o^2 + r_i^2)}/2$
$\rho$	Fluid density
$\omega$	Shaft angular velocity

Connections R and C are mechanical translational conserving ports corresponding to the cylinder rod and case, respectively. Connection W is a physical signal port through which shaft angular velocity is imported. The block directionality is adjustable and can be controlled with the **Cylinder orientation** parameter.

## Basic Assumptions and Limitations

- No inertial effects are considered in the model; that is, the angular velocity of the cylinder is assumed to be constant or changing at very low speed.
- Fluid inertia is not taken into account.
- Fluid compressibility is not taken into account.

## Parameters

### Piston outer radius

The default value is 0.1 m.

### Piston inner radius

The default value is 0.05 m.

### Fluid entry radius

The default value is 0.06 m.

### Fluid density

The default value is  $880 \text{ kg/m}^3$ .

### Cylinder orientation

Specifies block orientation with respect to the globally assigned positive direction. The block can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction. If positive velocity applied at port W exerts force in negative direction, set the parameter to Acts in negative direction. The default value is Acts in positive direction.

### Restricted Parameters

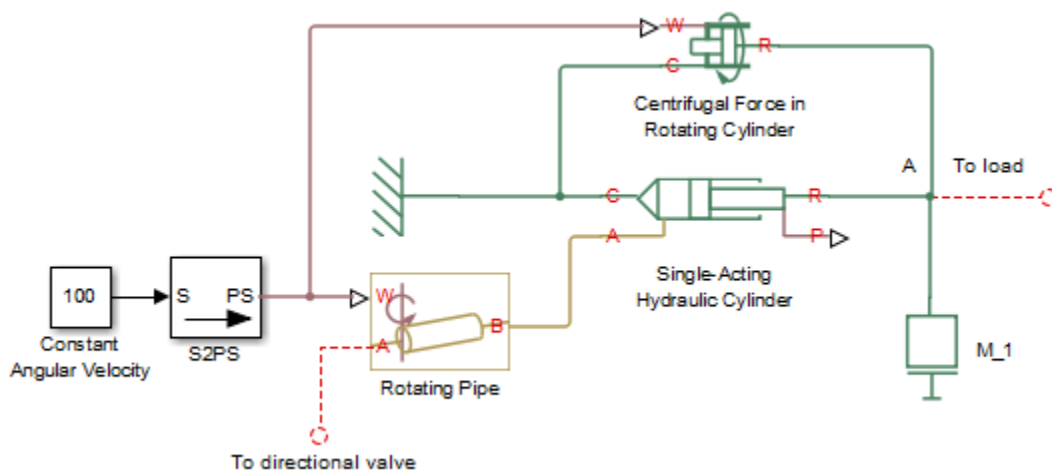
When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Cylinder orientation**

All other block parameters are available for modification.

## Examples

The following schematic diagram shows a model of a custom single-acting hydraulic cylinder built of the Single-Acting Hydraulic Cylinder, Rotating Pipe, and Centrifugal Force in Rotating Cylinder blocks.



The centrifugal force generated by the Centrifugal Force in Rotating Cylinder block sums up with that of the cylinder at node A. The Rotating Pipe block simulates the pipeline between the cylinder chamber and the channel in the center of a rotating shaft where the cylinder is installed.

## Ports

The block has the following ports:

R

Mechanical translational conserving port associated with the cylinder rod.

C

Mechanical translational conserving port associated with the cylinder clamping structure.

W

Physical signal port providing the angular velocity value.

## Version History

**Introduced in R2010a**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Rotating Pipe

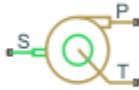
## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Centrifugal Pump

Centrifugal pump with choice of parameterization options

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Centrifugal Pump block represents a centrifugal pump of any type as a data-sheet-based model. Depending on data listed in the manufacturer's catalog or data sheet for your particular pump, you can choose one of the following model parameterization options:

- **By approximating polynomial** — Provide values for the polynomial coefficients. These values can be determined analytically or experimentally, depending on the data available. This is the default method.
- **By two 1D characteristics: P-Q and N-Q** — Provide tabulated data of pressure differential P and brake power N versus pump delivery Q characteristics. The pressure differential and brake power are determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By two 2D characteristics: P-Q-W and N-Q-W** — Provide tabulated data of pressure differential P and brake power N versus pump delivery Q characteristics at different angular velocities W. The pressure differential and brake power are determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

These parameterization options are further described in greater detail:

Connections P and T are hydraulic conserving ports associated with the pump outlet and inlet, respectively. Connection S is a mechanical rotational conserving port associated with the pump driving shaft. The block positive direction is from port T to port P. This means that the pump transfers fluid from T to P as its driving shaft S rotates in the globally assigned positive direction.

### Parameterizing the Pump by Approximating Polynomial

If you set the **Model parameterization** parameter to **By approximating polynomial**, the pump is parameterized with the polynomial whose coefficients are determined, analytically or experimentally, for a specific angular velocity depending on the data available. The pump characteristics at other angular velocities are determined using the affinity laws.

The approximating polynomial is derived from the Euler pulse moment equation, Equations 1 and 2, which for a given pump, angular velocity, and fluid can be represented as the following:

$$p_{ref} = k \cdot p_E - p_{HL} - p_D \quad (1-1)$$

where

$p_{ref}$	Pressure differential across the pump for the reference regime, characterized by the reference angular velocity and density
$k$	Correction factor. The factor is introduced to account for dimensional fluctuations, blade incongruity, blade volumes, fluid internal friction, and so on. The factor should be set to 1 if the approximating coefficients are determined experimentally.
$p_E$	Euler pressure
$p_{HL}$	Pressure loss due to hydraulic losses in the pump passages
$p_D$	Pressure loss caused by deviations of the pump delivery from its nominal (rated) value

The Euler pressure,  $p_E$ , is determined with the Euler equation for centrifugal machines in Equations 1 and 2 based on known pump dimensions. For an existing pump, operating at constant angular velocity and specific fluid, the Euler pressure can be approximated with the equation

$$p_E = \rho_{ref}(c_0 - c_1 \cdot q_{ref})$$

where

$\rho_{ref}$	Fluid density
$c_0, c_1$	Approximating coefficients. They can be determined either analytically from the Euler equation (Equations 1 and 2) or experimentally.
$q_{ref}$	Pump volumetric delivery at reference regime

The pressure loss due to hydraulic losses in the pump passages,  $p_{HL}$ , is approximated with the equation

$$p_{HL} = \rho_{ref} \cdot c_2 \cdot q_{ref}^2$$

where

$\rho_{ref}$	Fluid density
$c_2$	Approximating coefficient
$q_{ref}$	Pump volumetric delivery at reference regime

The blade profile is determined for a specific fluid velocity, and deviation from this velocity results in pressure loss due to inconsistency between the fluid velocity and blade profile velocity. This pressure loss,  $p_D$ , is estimated with the equation

$$p_D = \rho_{ref} \cdot c_3(q_D - q_{ref})^2$$

where

$\rho_{ref}$	Fluid density
$c_3$	Approximating coefficient
$q_{ref}$	Pump volumetric delivery at reference regime
$q_D$	Pump design delivery (nominal delivery)

The resulting approximating polynomial takes the form:

$$p_{ref} = \rho_{ref} \left( k(c_0 - c_1 q_{ref}) - c_2 q_{ref}^2 - c_3 (q_D - q_{ref})^2 \right) \quad (1-2)$$



The pump characteristics, approximated with four coefficients  $c_0$ ,  $c_1$ ,  $c_2$ , and  $c_3$ , are determined for a specific fluid and a specific angular velocity of the pump's driving shaft. These two parameters correspond, respectively, to the **Reference density** and **Reference angular velocity** parameters in the block dialog box. To apply the characteristics for another velocity  $\omega$  or density  $\rho$ , the affinity laws are used. With these laws, the delivery at reference regime, which corresponds to given pump delivery and angular velocity, is computed with the expression

$$q_{ref} = q \frac{\omega_{ref}}{\omega} \quad (1-3)$$

where  $q$  and  $\omega$  are the instantaneous values of the pump delivery and angular velocity. Then the pressure differential  $p_{ref}$  at reference regime computed with Equation 2 and converted into pressure differential  $p$  at current angular velocity and density

$$p = p_{ref} \cdot \left( \frac{\omega}{\omega_{ref}} \right)^2 \cdot \frac{\rho}{\rho_{ref}}$$

Equation 2 describes pump characteristic for  $\omega > 0$  and  $q \geq 0$ . Outside this range, the characteristic is approximated with the following relationships:

$$p = \begin{cases} -k_{leak} \cdot q & \text{for } \omega \leq 0 \\ p_{max} - k_{leak} \cdot q & \text{for } \omega > 0, q < 0 \\ -k_{leak} \cdot (q - q_{max}) & \text{for } \omega > 0, q > q_{max} \end{cases} \quad (1-4)$$

$$q_{max} = \frac{-b + \sqrt{b^2 + 4ac}}{2a}$$

$$a = (c_2 + c_3) \cdot \alpha^2$$

$$b = (k \cdot c_1 - 2c_3 \cdot q_D) \cdot \alpha$$

$$c = k \cdot c_0 - c_3 \cdot q_D^2$$

$$\alpha = \frac{\omega}{\omega_{ref}}$$

$$q_{max} = \rho \frac{1}{\alpha^2} (k \cdot c_0 - c_3 \cdot q_D^2)$$

where

$k_{leak}$	Leakage resistance coefficient
$q_{max}$	Maximum pump delivery at given angular velocity. The delivery is determined from Equation 2 at $p = 0$ .
$p_{max}$	Maximum pump pressure at given angular velocity. The pressure is determined from Equation 2 at $q = 0$ .
$k$	Correction factor, as described in Equation 1.

The hydraulic power at the pump outlet at reference conditions is

$$N_{hyd} = p_{ref} \cdot q_{ref}$$

The output hydraulic power at arbitrary angular velocity and density is determined with the affinity laws

$$N = N_{ref} \left( \frac{\omega}{\omega_{ref}} \right) \cdot \frac{\rho}{\rho_{ref}}$$

The power at the pump driving shaft consists of the theoretical hydraulic power (power before losses associated with hydraulic loss and deviation from the design delivery) and friction loss at the driving shaft. The theoretical hydraulic power is approximated using the Euler pressure

$$N_{hyd0} = p_{Eref} \cdot q_{ref} \cdot \left( \frac{\omega}{\omega_{ref}} \right)^3$$

where

$N_{hyd0}$	Pump theoretical hydraulic power
$p_{Eref}$	Euler pressure. The theoretical pressure developed by the pump before losses associated with hydraulic loss and deviation from the design delivery.

The friction losses are approximated with the relationship:

$$N_{fr} = (T_0 + k_p \cdot p) \cdot \omega$$

where

$N_{fr}$	Friction loss power
$T_0$	Constant torque at driving shaft associated with shaft bearings, seal friction, and so on
$k_p$	Torque-pressure relationship, which characterizes the influence of pressure on the driving shaft torque

The power and torque at the pump driving shaft (brake power  $N_{mech}$  and brake torque  $T$ ) are

$$N_{mech} = N_{hyd0} + N_{fr}$$

$$T = \frac{N_{mech}}{\omega}$$

The pump total efficiency  $\eta$  is computed as

$$\eta = \frac{N_{hyd}}{N_{mech}}$$

### Parameterizing the Pump by Pressure Differential and Brake Power Versus Pump Delivery

If you set the **Model parameterization** parameter to By two 1D characteristics: P-Q and N-Q, the pump characteristics are computed by using two one-dimensional table lookups: for the pressure differential based on the pump delivery and for the pump brake power based on the pump delivery. Both characteristics are specified at the same angular velocity  $\omega_{ref}$  (**Reference angular velocity**) and the same fluid density  $\rho_{ref}$  (**Reference density**).

To compute pressure differential at another angular velocity, affinity laws are used, similar to the first parameterization option. First, the new reference delivery  $q_{ref}$  is computed with the expression

$$q_{ref} = q \frac{\omega_{ref}}{\omega}$$

where  $q$  is the current pump delivery. Then the pressure differential across the pump at current angular velocity  $\omega$  and density  $\rho$  is computed as

$$p = p_{ref} \cdot \left( \frac{\omega}{\omega_{ref}} \right)^2 \cdot \frac{\rho}{\rho_{ref}}$$

where  $p_{ref}$  is the pressure differential determined from the P-Q characteristic at pump delivery  $q_{ref}$ .

Brake power is determined with the equation

$$N = N_{ref} \cdot \left( \frac{\omega}{\omega_{ref}} \right)^3 \cdot \frac{\rho}{\rho_{ref}}$$

where  $N_{ref}$  is the reference brake power obtained from the N-Q characteristic at pump delivery  $q_{ref}$ .

The torque at the pump driving shaft is computed with the equation  $T = N / \omega$ .

### Parameterizing the Pump by Pressure Differential and Brake Power Versus Pump Delivery at Different Angular Velocities

If you set the **Model parameterization** parameter to By two 2D characteristics: P-Q-W and N-Q-W, the pump characteristics are read out from two two-dimensional table lookups: for the pressure differential based on the pump delivery and angular velocity and for the pump brake power based on the pump delivery and angular velocity.

Both the pressure differential and brake power are scaled if fluid density  $\rho$  is different from the reference density  $\rho_{ref}$ , at which characteristics have been obtained

$$p = p_{ref} \cdot \frac{\rho}{\rho_{ref}}$$

$$N = N_{ref} \cdot \frac{\rho}{\rho_{ref}}$$

where  $p_{ref}$  and  $N_{ref}$  are the pressure differential and brake power obtained from the plots.

### Basic Assumptions and Limitations

- Fluid compressibility is neglected.
- The pump rotates in positive direction, with speed that is greater or equal to zero.
- The reverse flow through the pump is allowed only at still shaft.

## Ports

### Conserving

#### T – Suction port

isothermal liquid

Hydraulic conserving port associated with the pump suction, or inlet.

**P – Outlet port**

isothermal liquid

Hydraulic conserving port associated with the pump outlet.

**S – Shaft port**

isothermal liquid

Mechanical rotational conserving port associated with the pump driving shaft.

**Parameters****Model parameterization – Model configurations by pressure differential, brake power, and pump capacity**

By approximating polynomial (default) | By two 1D characteristics: P-Q and N-Q | By two 2D characteristics: P-Q-W and N-Q-W

Select one of the following methods for specifying the pump parameters:

- **By approximating polynomial** – Provide values for the polynomial coefficients. These values can be determined analytically or experimentally, depending on the data available. The relationship between pump characteristics and angular velocity is determined from the affinity laws.
- **By two 1D characteristics: P-Q and N-Q** – Provide tabulated data of pressure differential and brake power versus pump delivery characteristics. The pressure differential and brake power are determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods. The relationship between pump characteristics and angular velocity is determined from the affinity laws.
- **By two 2D characteristics: P-Q-W and N-Q-W** – Provide tabulated data of pressure differential and brake power versus pump delivery characteristics at different angular velocities. The pressure differential and brake power are determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

**First approximating coefficient – Coefficient  $c_0$  of the Euler pulse moment equation for pressure**

326.8 Pa/(kg/m<sup>3</sup>) (default)

Approximating coefficient  $c_0$  in the block description preceding. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Second approximating coefficient – Coefficient  $c_1$  of the Euler pulse moment equation for pressure**

3.104e4 Pa\*s/kg (default)

Approximating coefficient  $c_1$  in the block description preceding. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Third approximating coefficient – Coefficient  $c_2$  of the hydraulic losses calculation**

1.097e7 Pa\*s<sup>2</sup>/(kg\*m<sup>3</sup>) (default)

Approximating coefficient  $c_2$  in the block description preceding. This coefficient accounts for hydraulic losses in the pump. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Fourth approximating coefficient – Coefficient  $c_3$  that accounts for the difference in losses between nominal flow and flow through pump geometry**2.136e5 Pa\*s<sup>2</sup>/(kg\*m<sup>3</sup>) (default)

Approximating coefficient  $c_3$  in the block description preceding. This coefficient accounts for additional hydraulic losses caused by deviation from the nominal delivery. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Correction factor – Correction of Euler pressure calculation for reference pressure calculation**

0.8 (default)

The factor, denoted as  $k$  in the block description preceding, accounts for dimensional fluctuations, blade incongruity, blade volumes, fluid internal friction, and other factors that decrease Euler theoretical pressure. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Pump design delivery – Nominal pump capacity**

130 lpm (default)

The pump nominal delivery. The blades profile, pump inlet, and pump outlet are shaped for this particular delivery. Deviation from this delivery causes an increase in hydraulic losses. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Reference angular velocity – Shaft speed**

1770 rpm (default)

Angular velocity of the driving shaft, at which the pump characteristics are determined. This parameter is used if **Model parameterization** is set to By approximating polynomial or By two 1D characteristics: P-Q and N-Q.

**Reference density – Reference density**920 kg/m<sup>3</sup> (default)

Fluid density at which the pump characteristics are determined.

**Leak resistance – Coefficient for pressure outside of pump normal operating range**1e8 Pa/(m<sup>3</sup>/s) (default)

Leakage resistance coefficient (see Equation 4). This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Drive shaft torque – Shaft friction torque**

0.1 N\*m (default)

The friction torque on the shaft at zero velocity. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Torque-pressure coefficient – Relationship between pump pressure and shaft torque**

0.1e-5 N\*m/Pa (default)

The coefficient that provides relationship between torque and pump pressure. The default value is 1e-6 N\*m/Pa. This parameter is used if **Model parameterization** is set to By approximating polynomial.

**Pump delivery vector for Pressure differential – Capacity vector for tabular parameterization of pump pressure**

[0, 28, 90, 130, 154, 182] lpm (default)

Specify the vector of pump deliveries, as a one-dimensional array, to be used together with the vector of pressure differentials to specify the P-Q pump characteristic. The vector values must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. This parameter is used if **Model parameterization** is set to By two 1D characteristics: P-Q and N-Q.

**Pressure differential across pump vector – Pressure vector for tabular parameterization of pump pressure**

[2.6, 2.4, 2, 1.6, 1.2, .8] bar (default)

Specify the vector of pressure differentials across the pump as a one-dimensional array. The vector will be used together with the pump delivery vector to specify the P-Q pump characteristic. The vector must be of the same size as the pump delivery vector for the P-Q table. This parameter is used if **Model parameterization** is set to By two 1D characteristics: P-Q and N-Q.

**Pump delivery vector for Brake power – Capacity vector for tabular parameterization of brake power**

[0, 20, 40, 60, 80, 100, 120, 140, 160] lpm (default)

Specify the vector of pump deliveries, as a one-dimensional array, to be used together with the vector of the pump brake power to specify the N-Q pump characteristic. The vector values must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. This parameter is used if **Model parameterization** is set to By two 1D characteristics: P-Q and N-Q.

**Brake power vector – Brake power vector for tabular parameterization of brake power**

[220, 280, 310, 360, 390, 420, 480, 500, 550] W (default)

Specify the vector of pump brake power as a one-dimensional array. The vector will be used together with the pump delivery vector to specify the N-Q pump characteristic. The vector must be of the same size as the pump delivery vector for the N-Q table. This parameter is used if **Model parameterization** is set to By two 1D characteristics: P-Q and N-Q.

**Angular velocity vector,  $w$  – Shaft speed vector for tabular parameterization of pump pressure**

[3200, 3300, 3400, 3500] rpm (default)

Specify the vector of angular velocities, as a one-dimensional array, to be used for calculating both the pump P-Q-W and N-Q-W characteristics. The vector values must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. This parameter is used if **Model parameterization** is set to By two 2D characteristics: P-Q-W and N-Q-W.

**Pump delivery vector for Pressure differential,  $Q_p$  – Capacity vector for tabular parameterization of pump pressure**

[0, 50, 100, 150, 200, 250, 300, 350] lpm (default)

Specify the vector of pump deliveries, as a one-dimensional array, to be used together with the vector of angular velocities and the pressure differential matrix to specify the pump P-Q-W characteristic. The vector values must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. This parameter is used if **Model parameterization** is set to By two 2D characteristics: P-Q-W and N-Q-W.

**Pressure differential table,  $p(Q_p, \omega)$  – Pressure matrix for tabular parameterization of pump pressure**

[8.3, 8.8, 9.3, 9.9; 7.8, 8.3, 8.8, 9.4; 7.2, 7.6, 8.2, 8.7; 6.5, 7, 7.5, 8; 5.6, 6.1, 6.6, 7.1; 4.7, 5.2, 5.7, 6.2; 3.4, 4, 4.4, 4.9; 2.3, 2.7, 3.4, 3.6] bar (default)

Specify the pressure differentials across pump as an m-by-n matrix, where m is the number of the P-Q-W pump delivery values and n is the number of angular velocities. This matrix will define the pump P-Q-W characteristic together with the pump delivery and angular velocity vectors. Each value in the matrix specifies pressure differential for a specific combination of pump delivery and angular velocity. The matrix size must match the dimensions defined by the pump delivery and angular velocity vectors. This parameter is used if **Model parameterization** is set to By two 2D characteristics: P-Q-W and N-Q-W.

**Pump delivery vector for Brake power,  $Q_b$  – Capacity vector for tabular parameterization of brake power**

[0, 50, 100, 150, 200, 250, 300, 350] lpm (default)

Specify the vector of pump deliveries, as a one-dimensional array, to be used together with the vector of angular velocities and the brake power matrix to specify the pump N-Q-W characteristic. The vector values must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. This parameter is used if **Model parameterization** is set to By two 2D characteristics: P-Q-W and N-Q-W.

**Brake power table,  $W_b(Q_b, \omega)$  – Brake power matrix for tabular parameterization of brake power**

[1223, 1341, 1467, 1600; 1414, 1551, 1696, 1850; 1636, 1794, 1962, 2140; 1941, 2129, 2326, 2540; 2224, 2439, 2660, 2910; 2453, 2691, 2947, 3210; 2757, 3024, 3307, 3608; 2945, 3230, 3533, 3854] W (default)

Specify the pump brake power as an m-by-n matrix, where m is the number of the N-Q-W pump delivery values and n is the number of angular velocities. This matrix will define the pump N-Q-W characteristic together with the pump delivery and angular velocity vectors. Each value in the matrix specifies brake power for a specific combination of pump delivery and angular velocity. The matrix size must match the dimensions defined by the pump delivery and angular velocity vectors. This parameter is used if **Model parameterization** is set to By two 2D characteristics: P-Q-W and N-Q-W.

**Angular speed threshold for flow reversal – Shaft speed threshold region for flow reversal**

1e-9 (default)

Shaft angular velocity that indicates the transition threshold between forward and reverse flow. A transition region is defined around 0 rad/s between the positive and negative values of the angular velocity threshold. Within this transition region, the computed leakage flow rate and friction torque

are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

### **Interpolation method — Tabular interpolation**

Linear (default) | Smooth

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve or surface with continuous first-order derivatives.

This parameter is used if **Model parameterization** is set to **By two 1D characteristics: P-Q and N-Q** or **By two 2D characteristics: P-Q-W and N-Q-W**. For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

### **Extrapolation method — Tabular extrapolation**

Linear (default) | Nearest

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

This parameter is used if **Model parameterization** is set to **By two 1D characteristics: P-Q and N-Q** or **By two 2D characteristics: P-Q-W and N-Q-W**. For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

## **Version History**

**Introduced in R2007a**

## **References**

[1] T.G. Hicks, T.W. Edwards, *Pump Application Engineering*, McGraw-Hill, NY, 1971

[2] I.J. Karassic, J.P. Messina, P. Cooper, C.C. Heald, *Pump Handbook*, Third edition, McGraw-Hill, NY, 2001

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.



## **See Also**

Fixed-Displacement Pump | Variable-Displacement Pressure-Compensated Pump | Variable-Displacement Pump

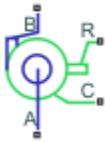
## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Centrifugal Pump (IL)

Centrifugal pump in isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors

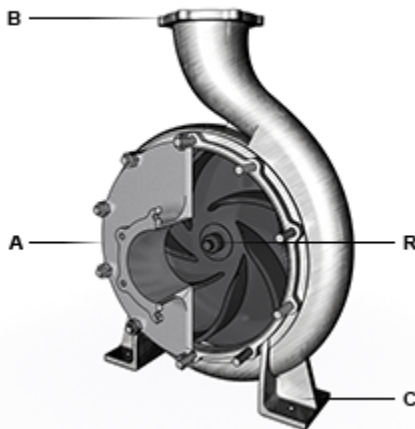


## Description

The Centrifugal Pump (IL) block represents a centrifugal pump that transfers energy from the shaft to a fluid in an isothermal liquid network. The pressure differential and mechanical torque are functions of the pump head and brake power, which depend on pump capacity. You can parameterize the pump analytically or by linear interpolation of tabulated data. The pump affinity laws define the core physics of the block, which scale the pump performance to the ratio of the current to the reference values of the pump angular velocity and impeller diameter.

By default, the flow and pressure gain are from port **A** to port **B**. Port **C** represents the pump casing, and port **R** represents the pump shaft. You can specify the normal operating shaft direction in the **Mechanical orientation** parameter. If the shaft begins to spin in the opposite direction, the pressure difference across the block drops to zero.

The figure shows the location of the block ports on a typical centrifugal pump.



## Port Configuration

### Analytical Parameterization: Capacity, Head, and Brake Power

When you set, **Pump parameterization** to Capacity, head, and brake power at reference shaft speed, the block calculates the pressure gain over the pump as a function of the pump affinity laws and the reference pressure differential:

$$p_B - p_A = \Delta H_{ref} \rho g \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2,$$

where:

- $g$  is the gravitational acceleration.
- $\Delta H$  is the reference pump head, which the block derives from a quadratic fit of the pump pressure differential between the values of the **Maximum head at zero capacity**, **Nominal head**, and **Maximum capacity at zero head** parameters.
- $\omega$  is the shaft angular velocity,  $\omega_R - \omega_C$ .
- $\omega_{ref}$  is the value of the **Reference shaft speed** parameter.
- $\frac{D}{D_{ref}}$  is the value of the **Impeller diameter scale factor** parameter. This block does not reflect changes in pump efficiency due to pump size.
- $\rho$  is the network fluid density.

The shaft torque is:

$$\tau = W_{brake,ref} \frac{\omega^2}{\omega_{ref}^3} \left( \frac{D}{D_{ref}} \right)^5.$$

The reference brake power,  $W_{brake,ref}$ , is calculated as capacity·head/efficiency. The pump efficiency curve is quadratic with its peak corresponding to the **Nominal brake power** parameter, and it falls to zero when capacity is zero or maximum as the pump curve figure demonstrates.

The block calculates the reference capacity as:

$$q_{ref} = \frac{\dot{m}}{\rho} \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

You can choose to be warned when the block flow rate becomes negative or exceeds the maximum pump capacity by setting **Check if operating beyond normal pump operation** to 0n.

### 1-D Tabulated Data Parameterization: Head and Brake Power as a Function of Capacity

When you set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed, the pressure gain over the pump functions with the **Reference head vector** parameter,  $\Delta H_{ref}$ , which is a function of the reference capacity,  $q_{ref}$ :

$$\Delta p = \rho g \Delta H_{ref}(q_{ref}) \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2,$$

where  $g$  is the gravitational acceleration.

The block bases the shaft torque on the **Reference brake power vector** parameter,  $W_{ref}$ , which is a function of the reference capacity:

$$\tau = W_{ref}(q_{ref}) \frac{\omega^2}{\omega_{ref}^3} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where  $\rho_{ref}$  is the **Reference density** parameter. The reference capacity is:

$$q_{ref} = \frac{\dot{m}}{\rho} \left( \frac{\omega_{ref}}{\omega} \right) \left( \frac{D_{ref}}{D} \right)^3,$$

which the block uses to interpolate the values of the **Reference capacity vector**, **Reference head vector**, and **Reference brake power vector** parameters as a function of  $q_{ref}$ .

When the simulation is outside the range of the provided tables, the block extrapolates head based on the average slope of the pump curves and brake power to the nearest point.

## 2-D Tabulated Data Parameterization: Head and Brake Power as a Function of Capacity and Shaft Speed

When you set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed, the pressure gain over the pump is a function of the **Head table**, **H(q,w)** parameter,  $\Delta H_{ref}$ , which is a function of the reference capacity,  $q_{ref}$ , and the shaft speed,  $\omega$ :

$$\Delta p = \rho g \Delta H_{ref}(q_{ref}, \omega) \left( \frac{D}{D_{ref}} \right)^2.$$

The shaft torque is a function of the **Brake power table**, **Wb(q,w)** parameter,  $W_{ref}$ , which is a function of the reference capacity,  $q_{ref}$ , and the shaft speed,  $\omega$ :

$$\tau = \frac{W_{ref}(q_{ref}, \omega)}{\omega} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5.$$

The reference capacity is:

$$q_{ref} = \frac{\dot{m}}{\rho} \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates head based on the average slope of the pump curves and brake power to the nearest point.

### Missing Data

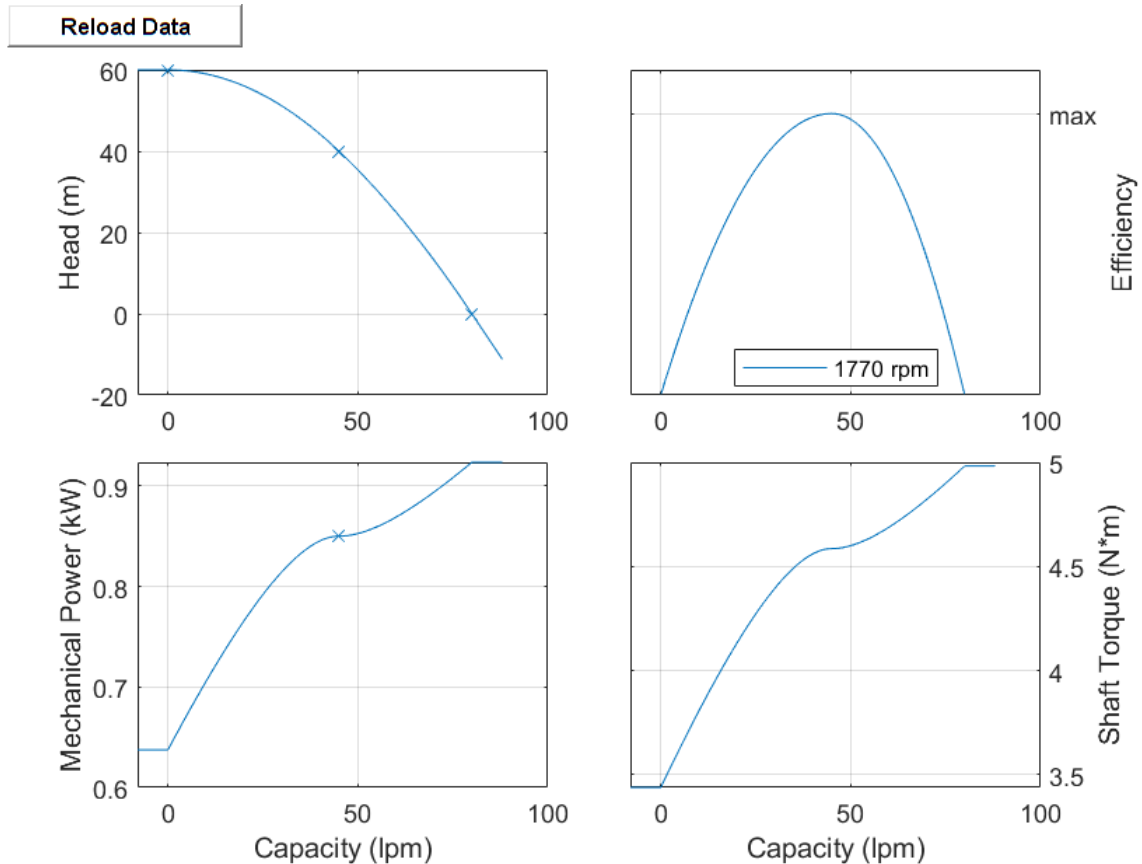
If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table**, **H(q,w)** and **Brake power table**, **Wb(q,w)** parameters must match each other.
- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

## Visualizing the Pump Curve

You can check the parameterized pump performance by plotting the head, power, efficiency, and torque as a function of the flow. To generate a plot of the current pump settings, right-click on the block and select **Fluids > Plot Pump Characteristics**. If you change settings or data, click **Apply** on the block parameters and click **Reload Data** on the pump curve figure.

The default block parameterization results in these plots:



## Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.

- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see “List of Pre-Parameterized Components”.

### **Assumptions and Limitations**

- If the shaft rotates opposite to the specified mechanical orientation, pressure difference across the block drops to zero and the results may not be accurate.
- The block does not account for dynamic pressure in the pump. The block only considers pump head due to static pressure.
- Pre-defined parameterizations use available data and the block fills in missing data where necessary. Validate your model against expected results.

## **Ports**

### **Conserving**

#### **A — Pump inlet**

isothermal liquid

Isothermal liquid conserving port associated with the fluid inlet.

#### **B — Pump outlet**

isothermal liquid

Thermal liquid conserving port associated with the fluid outlet.

#### **R — Impeller shaft**

mechanical rotational

Mechanical rotational conserving port associated with the shaft.

#### **C — Pump casing**

mechanical rotational

Mechanical rotational conserving port associated with the case.

## **Parameters**

### **Pump parameterization — Head and brake power parameterization**

Capacity, head, and brake power at reference shaft speed (default) | 1D tabulated data - head and brake power vs. capacity at reference shaft speed | 2D tabulated data - head and brake power vs. capacity and shaft speed

Parameterization of the pump head and brake power, specified as:

- Capacity, head, and brake power at reference shaft speed: Parameterize pump pressure gain and shaft torque with an analytical formula.
- 1D tabulated data - head and brake power vs. capacity at reference shaft speed: Parameterize head and brake power from tabulated data of the head and brake power at a given capacity.
- 2D tabulated data - head and brake power vs. capacity and shaft speed: Parameterize head and brake power from tabulated data of the head and brake power at a given capacity and shaft speed.

### **Nominal capacity — Pump volumetric flow rate**

45 lpm (default) | positive scalar

Nominal pump volumetric flow rate at a reference shaft angular velocity.

#### **Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

### **Nominal head — Pump head**

40 m (default) | positive scalar

Nominal pump pressure differential, normalized by gravity and the fluid density, at a reference shaft angular velocity.

#### **Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

### **Nominal brake power — Pump power**

0.85 kW (default) | positive scalar

Nominal mechanical shaft power at a reference angular velocity.

#### **Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

### **Maximum head at zero capacity — Maximum pump head with no flow**

60 m (default) | positive scalar

Maximum pump head with no flow at a reference angular velocity. This parameter determines the reference pressure differential over the pump, which the block uses to fit a quadratic equation for pressure in addition to the **Nominal capacity**, **Nominal head**, and **Maximum capacity at zero head** parameters.

#### **Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

### **Maximum capacity at zero head — Maximum flow rate with zero head**

80 lpm (default) | positive scalar

Maximum fluid load with zero head at a reference angular velocity. This parameter determines the reference pressure differential over the pump, which the block uses to fit a quadratic equation for pressure in addition to the **Nominal capacity**, **Nominal head**, and **Maximum head at zero capacity** parameters.

#### Dependencies

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

#### Reference shaft speed — Reference shaft angular velocity for affinity law calculations

1770 rpm | 3500 rpm | positive scalar

Reference angular velocity for affinity law calculations. The default value depends on the **Pump parameterization** setting.

#### Dependencies

To enable this parameter, set **Pump parameterization** to either:

- Capacity, head, and brake power at reference shaft speed.
- 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

#### Reference capacity vector — Volumetric flow rate

[16.67, 30, 40, 53.33, 66.67, 83.33] lpm (default) | vector

Vector of volumetric flow rates for the tabular parameterization of the pump head or brake power. The elements in this vector correspond one-to-one with the elements in the **Reference head vector** and **Reference brake power vector** parameters. In normal operating conditions the elements in this parameter are nonnegative, but the block does accept negative values. Negative capacity is a non-normal operating condition that may arise from certain situations.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

#### Reference head vector — Pump head vector

[50, 47.5, 45, 40, 35, 25] m (default) | vector

Vector of the pump head values for the 1-D tabular parameterization of the pump head and brake power. This parameter corresponds one-to-one with the **Reference capacity vector** parameter. In normal operating conditions the elements in this parameter are nonnegative, but the block does accept negative values. Negative head, or pressure drop, is possible in non-normal operating conditions at the end of the vector.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

#### Reference brake power vector — Pump brake power vector

[.6, .75, .85, .93, .98, .99] kW (default) | vector

Vector of pump brake power values for the 1-D tabular parameterization of the pump head and brake power. This parameter corresponds one-to-one with the **Reference capacity vector** parameter. In



normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative brake power is possible in non-normal operating conditions at the end of the vector.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

#### Capacity vector, $q$ – Volumetric displacement vector

[16.67, 23.33, 30, 40, 53.33, 60] lpm (default) | vector

Vector of volumetric flow rates for the tabular parameterization of the pump head. This vector forms an independent axis with the **Shaft speed vector,  $w$**  parameter for the 2-D **Head table,  $H(q,w)$**  and **Brake power table,  $Wb(q,w)$**  parameters. The vector elements must be listed in ascending order. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative capacity is a non-normal operating condition that may arise from certain situations.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

#### Shaft speed vector, $w$ – Angular velocity vector

[2450, 2800, 3150, 3500] rpm (default) | vector

Vector of shaft angular velocity values for the tabular parameterization of the pump head. This vector forms an independent axis with the **Capacity vector,  $q$**  parameter for the 2-D **Head table,  $H(q,w)$**  and **Brake power table,  $Wb(q,w)$**  parameters. The vector elements must be listed in ascending order and must be greater than 0.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

#### Head table, $H(q,w)$ – Pump head matrix

[25, 32.7, 42.5, 50; 24, 31.7, 41, 49; 22.7, 30.5, 39, 47.5; 20, 28, 36, 45; 15.7, 24, 32, 40; 12.5, 21, 29.5, 37.5] m (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of pump head values at the specified volumetric flow rate and angular velocity. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative head, or pressure drop, is possible in non-normal operating conditions at the bottom of the table. The block employs linear interpolation between the table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Capacity vector,  $q$**  parameter.
- $N$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. All rows must be in strictly ascending order.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table,  $H(q,w)$**  and **Brake power table,  $W_b(q,w)$**  parameters must match each other.
- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

#### Brake power table, $W_b(q,w)$ — Pump brake power matrix

[.28, .38, .5, .6; .31, .41, .55, .68; .33, .44, .6, .75; .36, .48, .65, .83; .38, .53, .72, .93; .39, .55, .75, .97] kW (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of pump brake power values at the specified volumetric flow rate and angular velocity. In normal operating conditions these values are nonnegative, but the block does accept negative values. The block employs linear interpolation between the table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Capacity vector,  $q$**  parameter.
- $N$  is the number of vector elements in the **Shaft speed vector,  $w$**  parameter. All rows must be in strictly ascending order.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table,  $H(q,w)$**  and **Brake power table,  $W_b(q,w)$**  parameters must match each other.
- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

#### Reference density — Fluid density for given pump performance data

998 kg/m<sup>3</sup> (default) | positive scalar

Reference fluid density. The reference or data sheet typically specifies this value. This parameter scales the pump performance between different fluids.

#### Dependencies

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed or 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Impeller diameter scale factor — Ratio of model diameter to reference diameter for affinity law calculations**

1 (default) | positive scalar

Ratio of the model-to-reference diameter for affinity law calculations. Modify this value if there is a difference between your reference and the system impeller diameters, such as when testing pump scaling. For system pumps smaller than the reference pump, use a value less than one. For system pumps larger than the reference pump, use a value greater than one. The block does not reflect changes in pump efficiency due to pump size.

**Mechanical orientation — Shaft normal rotational direction**

Positive angular velocity of port R relative to port C corresponds to normal pump operation (default) | Negative angular velocity of port R relative to port C corresponds to normal pump operation

Shaft rotational direction for flow from port **A** to **B**.

**Check if operating beyond normal pump operation — Option to notify when block is beyond operating bounds**

Warning (default) | None | Error

Option to notify if the block operates outside of the normal pump boundary. This situation occurs when the flow rate through the pump is negative or beyond the maximum capacity of the pump.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

## Version History

**Introduced in R2020a****Extend performance beyond normal operating conditions**

Both the 1-D and 2-D parameterizations now allow negative values. When simulation is outside the range of the provided table, the block extrapolates the pump head based on the average slope of the pump curves.

You can now use NaN elements where pump data is unavailable. These 2-D tabulated parameters support contiguous NaN elements in the lower-left portion of the table:

- **Head table  $H(q,w)$**
- **Brake power table,  $W_b(q,w)$**

For each block, if the shaft rotates opposite to the specified mechanical orientation, the pressure difference across the block drops to zero and the results may not be accurate.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Centrifugal Pump (TL) | Variable-Displacement Pump (IL) | Pressure-Compensated Pump (IL) | Fixed-Displacement Pump (IL)

# Centrifugal Pump (TL)

Centrifugal pump in thermal liquid network

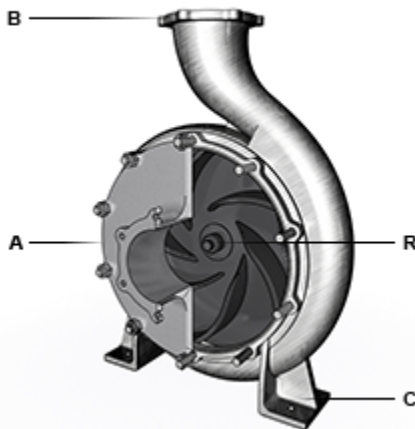
**Library:** Simscape / Fluids / Thermal Liquid / Pumps & Motors



## Description

The Centrifugal Pump (TL) block represents a centrifugal pump that transfers energy from the shaft to a fluid in a thermal liquid network. The pressure differential and mechanical torque are functions of the pump head and brake power, which depend on pump capacity. You can parameterize the pump analytically or by linear interpolation of tabulated data. The pump affinity laws define the core physics of the block, which scale the pump performance to the ratio of the current to the reference values of the pump angular velocity and impeller diameter.

By default, the flow and pressure gain are from port **A** to port **B**. Port **C** represents the pump casing, and port **R** represents the pump shaft. You can specify the normal operating shaft direction in the **Mechanical orientation** parameter. If the shaft begins to spin in the opposite direction, the pressure difference across the pump drops to zero.



## Port Configuration

### Analytical Parameterization: Capacity, Head, and Brake Power

The block calculates the pressure gain over the pump as a function of the pump affinity laws and the reference pressure differential:

$$p_B - p_A = \Delta H_{ref} \rho g \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2,$$

where:

- $\Delta p_{ref}$  is the reference pressure gain, which is determined from a quadratic fit of the pump pressure differential between the **Maximum head at zero capacity**, **Nominal head**, and **Maximum capacity at zero head**.
- $\omega$  is the shaft angular velocity,  $\omega_R - \omega_C$ .
- $\omega_{ref}$  is the value of the **Reference shaft speed** parameter.
- $\frac{D}{D_{ref}}$  is the value of the **Impeller diameter scale factor** parameter. This block does not reflect changes in pump efficiency due to pump size.
- $\rho$  is the network fluid density.

The shaft torque is:

$$\tau = W_{brake,ref} \frac{\omega^2}{\omega_{ref}^3} \left( \frac{D}{D_{ref}} \right)^5.$$

The reference brake power,  $W_{brake,ref}$ , is calculated as capacity·head/efficiency. The pump efficiency curve is quadratic with its peak corresponding to the **Nominal brake power** parameter, and it falls to zero when capacity is zero or maximum as the pump curve demonstrates.

The block calculates the reference capacity as:

$$q_{ref} = \frac{\dot{m}}{\rho} \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

### 1-D Tabulated Data Parameterization: Head and Brake Power as a Function of Capacity

You can parameterize the pump performance as a 1-D function of capacity. The pressure gain over the pump functions with the **Reference head vector** parameter,  $\Delta H_{ref}$ , which is a function of the reference capacity,  $Q_{ref}$ :

$$\Delta p = \rho g \Delta H_{ref}(Q_{ref}) \frac{\omega^2}{\omega_{ref}^2} \left( \frac{D}{D_{ref}} \right)^2,$$

where:

- $\omega$  is the shaft angular velocity.
- $\rho$  is the fluid density.
- $g$  is the gravitational acceleration.

This is derived from the affinity law that relates head and angular velocity:

$$\frac{\Delta H_{ref}}{\Delta H} = \frac{\omega_{ref}^2}{\omega^2} \left( \frac{D}{D_{ref}} \right)^2,$$

where  $\Delta H$  is the pump head.

The block bases the shaft torque on the **Reference brake power vector** parameter,  $P_{ref}$ , which is a function of the reference capacity,  $Q_{ref}$ .

$$T = P_{ref}(Q_{ref}) \frac{\omega^2}{\omega_{ref}^3} \frac{\rho}{\rho_{ref}} \left( \frac{D}{D_{ref}} \right)^5,$$

where  $\rho_{ref}$  is the **Reference density** parameter.

This equation is a formulation of the affinity law that relates brake power and angular velocity:

$$\frac{P_{ref}}{P} = \frac{\omega_{ref}^3}{\omega^3} \frac{\rho_{ref}}{\rho} \left( \frac{D}{D_{ref}} \right)^5.$$

The reference capacity is:

$$Q_{ref} = \frac{\dot{m}}{\rho} \frac{\omega_{ref}}{\omega} \left( \frac{D}{D_{ref}} \right)^3,$$

where  $\dot{m}$  is the mass flow rate at the pump inlet.

When the simulation is outside the range of the provided tables, the block extrapolates head based on the average slope of the pump curves and brake power to the nearest point.

## 2-D Tabulated Data Parameterization: Head and Brake Power as a Function of Capacity and Shaft Speed

You can parameterize the pump performance as a 2-D function of capacity and shaft angular velocity. The pressure gain over the pump is a function of the **Head table,  $\mathbf{H}(\mathbf{Q}, \mathbf{w})$**  parameter,  $\Delta H_{ref}$ , which is a function of the reference capacity,  $Q_{ref}$ , and the shaft speed,  $\omega$ :

$$\Delta p = \rho g \Delta H_{ref}(Q_{ref}, \omega) \left( \frac{D}{D_{ref}} \right)^2.$$

The shaft torque is a function of the **Brake power table,  $\mathbf{Wb}(\mathbf{q}, \mathbf{w})$**  parameter,  $P_{ref}$ , which is a function of the reference capacity,  $Q_{ref}$ , and the shaft speed,  $\omega$ :

$$T = \frac{P_{ref}(Q_{ref}, \omega)}{\omega} \frac{\rho}{\rho_{ref}} \left( \frac{D}{D_{ref}} \right)^5.$$

The reference capacity is:

$$Q_{ref} = \frac{\dot{m}}{\rho} \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates head based on the average slope of the pump curves and brake power to the nearest point.

### Missing Data

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

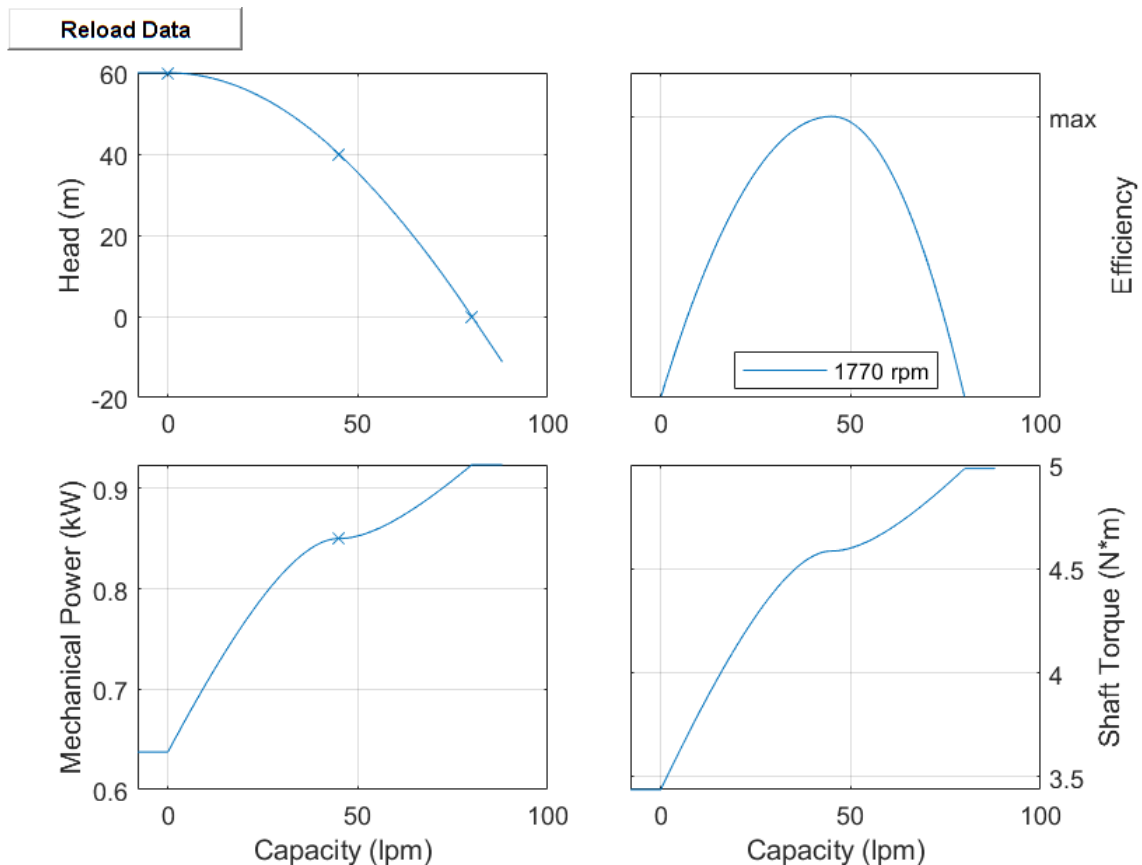
- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table,  $\mathbf{H}(\mathbf{q}, \mathbf{w})$**  and **Brake power table,  $\mathbf{Wb}(\mathbf{q}, \mathbf{w})$**  parameters must match each other.

- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

### Visualizing the Pump Curve

You can check the parameterized pump performance by plotting the head, power, efficiency, and torque as a function of the flow. To generate a plot of the current pump settings, right-click on the block and select **Fluids > Plot Pump Characteristics**. If you change settings or data, click **Apply** on the block parameters and click **Reload Data** on the pump curve figure.

The default block parameterization results in these plots:



### Energy Balance

Mechanical work is a result of the energy exchange from the shaft to the fluid. The governing energy balance equation is:

$$\phi_A + \phi_B + P_{hydro} = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

The pump hydraulic power is a function of the pressure difference between pump ports:



$$P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$$

### Assumptions and Limitations

- If the shaft rotates opposite to the specified mechanical orientation, pressure difference across the block drops to zero and the results may not be accurate.
- The block does not account for dynamic pressure in the pump. The block only considers pump head due to static pressure.

### Ports

#### Conserving

##### A – Pump inlet

thermal liquid

Thermal liquid conserving port associated with the fluid.

##### B – Pump outlet

thermal liquid

Thermal liquid conserving port associated with the fluid.

##### R – Impeller shaft

mechanical rotational

Mechanical rotational conserving port associated with the shaft.

##### C – Pump casing

mechanical rotational

Mechanical rotational conserving port associated with the case.

### Parameters

#### Pump parameterization – Head and brake power parameterization

Capacity, head, and brake power at reference shaft speed (default) | 1D tabulated data - head and brake power vs. capacity at reference shaft speed | 2D tabulated data - head and brake power vs. capacity and shaft speed

Parameterization of the pump head and brake power, specified as:

- Capacity, head, and brake power at reference shaft speed: Parameterize pump pressure gain and shaft torque with an analytical formula.
- 1D tabulated data - head and brake power vs. capacity at reference shaft speed: Parameterize head and brake power from tabulated data of the head and brake power at a given capacity.
- 2D tabulated data - head and brake power vs. capacity and shaft speed: Parameterize head and brake power from tabulated data of the head and brake power at a given capacity and shaft speed.

**Nominal capacity — Pump volumetric flow rate**

45 lpm (default) | positive scalar

Nominal pump volumetric flow rate at a reference shaft angular velocity.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

**Nominal head — Pump head**

40 m (default) | positive scalar

Nominal pump pressure differential, normalized by gravity and the fluid density, at a reference shaft angular velocity.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

**Nominal brake power — Pump power**

0.85 kW (default) | positive scalar

Nominal mechanical shaft power at a reference angular velocity.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

**Maximum head at zero capacity — Maximum pump head with no flow**

60 m (default) | positive scalar

Maximum pump head with no flow at a reference angular velocity. This parameter determines the reference pressure differential over the pump, which the block uses to fit a quadratic equation for pressure in addition to the **Nominal capacity**, **Nominal head**, and **Maximum capacity at zero head** parameters.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

**Maximum capacity at zero head — Maximum flow rate with zero head**

80 lpm (default) | positive scalar

Maximum fluid load with zero head at a reference angular velocity. This parameter determines the reference pressure differential over the pump, which the block uses to fit a quadratic equation for pressure in addition to the **Nominal capacity**, **Nominal head**, and **Maximum head at zero capacity** parameters.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

**Reference shaft speed — Reference shaft angular velocity for affinity law calculations**

1770 rpm | 3500 rpm | positive scalar

Reference angular velocity for affinity law calculations. The default value depends on the **Pump parameterization** setting.

**Dependencies**

To enable this parameter, set **Pump parameterization** to either:

- Capacity, head, and brake power at reference shaft speed.
- 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

**Reference capacity vector — Volumetric flow rate**

[16.67, 30, 40, 53.33, 66.67, 83.33] lpm (default) | vector

Vector of volumetric flow rates for the tabular parameterization of the pump head or brake power. The elements in this vector correspond one-to-one with the elements in the **Reference head vector** and **Reference brake power vector** parameters. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative capacity is a non-normal operating condition that may arise from certain situations.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

**Reference head vector — Pump head vector**

[50, 47.5, 45, 40, 35, 25] m (default) | vector

Vector of pump head values for the 1-D tabular parameterization of the pump head and brake power. This parameter corresponds one-to-one with the **Reference capacity vector** parameter. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative head, or pressure drop, is possible in non-normal operating conditions at the end of the vector.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

**Reference brake power vector — Pump brake power vector**

[.6, .75, .85, .93, .98, .99] kW (default) | vector

Vector of pump brake power values for the 1-D tabular parameterization of the pump head and brake power. This parameter corresponds one-to-one with the **Reference capacity vector** parameter. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative brake power is possible in non-normal operating conditions at the end of the vector.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed.

**Capacity vector,  $q$  — Volumetric displacement vector**

[16.67, 23.33, 30, 40, 53.33, 60] lpm (default) | vector

Vector of volumetric flow rates for the tabular parameterization of the pump head. This vector forms an independent axis with the **Shaft speed vector,  $w$**  parameter for the 2-D **Head table,  $H(q,w)$**  and **Brake power table,  $Wb(q,w)$**  parameters. The vector elements must be listed in ascending order. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative capacity is a non-normal operating condition that may arise from certain situations.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Shaft speed vector,  $w$  — Angular velocity vector**

[2450, 2800, 3150, 3500] rpm (default) | vector

Vector of shaft angular velocity values for the tabular parameterization of the pump head. This vector forms an independent axis with the **Capacity vector,  $q$**  parameter for the 2-D **Head table,  $H(q,w)$**  and **Brake power table,  $Wb(q,w)$**  parameters. The vector elements must be listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Head table,  $H(q,w)$  — Pump head matrix**[25, 32.7, 42.5, 50; 24, 31.7, 41, 49; 22.7, 30.5, 39, 47.5; 20, 28, 36, 45; 15.7, 24, 32, 40; 12.5, 21, 29.5, 37.5] m (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of pump head values at the specified volumetric flow rate and angular velocity. In normal operating conditions, the elements in this parameter are nonnegative, but the block does accept negative values. Negative head, or pressure drop, is possible in non-normal operating conditions at the bottom of the table. The block employs linear interpolation between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Capacity vector,  $q$**  parameter.
- $N$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. All rows must be in strictly ascending order.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table,  $H(q,w)$**  and **Brake power table,  $Wb(q,w)$**  parameters must match each other.
- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Brake power table,  $W_b(q,w)$  — Pump brake power matrix**

[.28, .38, .5, .6; .31, .41, .55, .68; .33, .44, .6, .75; .36, .48, .65, .83; .38, .53, .72, .93; .39, .55, .75, .97] kW (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of pump brake power values at the specified volumetric flow rate and angular velocity. In normal operating conditions these values are nonnegative, but the block does accept negative values. Linear interpolation is employed between table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Capacity vector,  $q$**  parameter.
- *N* is the number of vector elements in the **Shaft speed vector,  $w$**  parameter. All rows must be in strictly ascending order.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the pump curves. Do not use artificial numerical values because these values distort pump behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Head table,  $H(q,w)$**  and **Brake power table,  $W_b(q,w)$**  parameters must match each other.
- NaN elements must be located in the lower-left portion of the table, which corresponds to the highest capacity and lowest shaft speed.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Reference density — Fluid density for given pump performance data**

998 kg/m<sup>3</sup> (default) | positive scalar

Reference fluid density. The reference or data sheet typically specifies this value. This parameter scales the pump performance between different fluids.

**Dependencies**

To enable this parameter, set **Pump parameterization** to 1D tabulated data - head and brake power vs. capacity at reference shaft speed or 2D tabulated data - head and brake power vs. capacity and shaft speed.

**Impeller diameter scale factor — Ratio of model diameter to reference diameter for affinity law calculations**

1 (default) | positive scalar

Ratio of the model-to-reference diameter for affinity law calculations. Modify this value if there is a difference between your reference and the system impeller diameters, such as when testing pump scaling. For system pumps smaller than the reference pump, use a value less than one. For system pumps larger than the reference pump, use a value greater than one. The block does not reflect changes in pump efficiency due to pump size.

**Mechanical orientation — Shaft normal rotational direction**

Positive angular velocity of port R relative to port C corresponds to normal pump operation (default) | Negative angular velocity of port R relative to port C corresponds to normal pump operation

Shaft rotational direction for flow from port **A** to **B**.

**Check if operating beyond normal pump operation — Option to notify when block is beyond operating bounds**

Warning (default) | None | Error

Option to notify if the block operates outside of the normal pump boundary. This situation occurs when the flow rate through the pump is negative or beyond the maximum capacity of the pump.

**Dependencies**

To enable this parameter, set **Pump parameterization** to Capacity, head, and brake power at reference shaft speed.

## Version History

**Introduced in R2018a**

**Extend performance beyond normal operating conditions**

Both the 1-D and 2-D parameterizations now allow negative values. When simulation is outside the range of the provided table, the block extrapolates the pump head based on the average slope of the pump curves.

You can now use NaN elements where pump data is unavailable. These 2-D tabulated parameters support contiguous NaN elements in the lower-left portion of the table:

- **Head table  $H(q,w)$**
- **Brake power table,  $W_b(q,w)$**

For each block, if the shaft rotates opposite to the specified mechanical orientation, the pressure difference across the block drops to zero and the results may not be accurate.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Centrifugal Pump (IL) | Fixed-Displacement Pump (TL) | Variable-Displacement Pump (TL)

# Check Valve

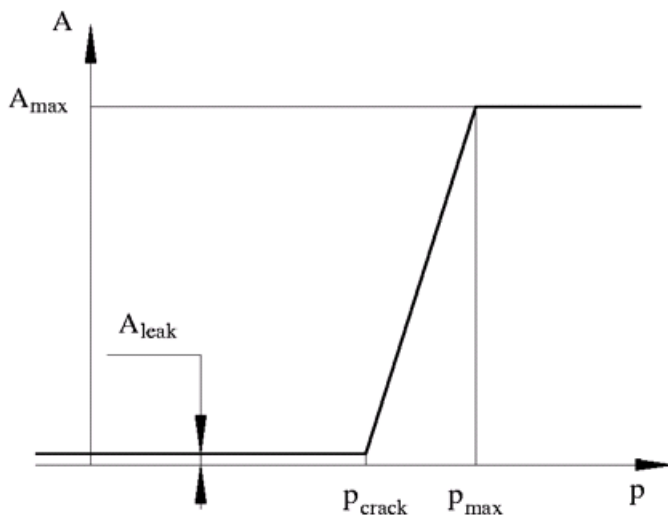
Hydraulic valve that allows flow in one direction only

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Directional Valves



## Description

The Check Valve block represents a hydraulic check valve as a data-sheet-based model. The check valve permits flow in one direction and blocks it in the opposite direction. This figure shows the typical dependency between the valve passage area  $A$  and the pressure differential across the valve  $\Delta p = p_A - p_B$ .



The valve remains closed when the pressure differential across the valve is lower than the valve cracking pressure. When cracking pressure is reached, the valve control member, such as a spool or poppet, is forced off its seat, thus creating a passage between the inlet and outlet. If the flow rate is high enough and pressure continues to rise, the area increases until the control member reaches its maximum displacement. At this moment, the valve passage area is at its maximum. The catalogs and manufacturer data sheets generally provide the valve maximum area and the cracking and maximum pressures.

The leakage area is also required to characterize the valve. The **Leakage area** parameter accounts for possible leakage and maintains the numerical integrity of the circuit, by preventing a portion of the system from getting isolated after the valve is completely closed. Because isolated parts of the system could affect computational efficiency or cause failure of computation, the parameter value must be greater than zero.

By default, the block does not include the valve opening dynamics, and the valve sets its opening area directly as a function of pressure:

$$A = A(p).$$

Adding valve opening dynamics provides continuous behavior that is more physically realistic, and is helpful in situations with rapid valve opening and closing. The pressure-dependent orifice passage area  $A(p)$  in the block equations then becomes the steady-state area, and the instantaneous orifice passage area in the flow equation is:

$$A(t = 0) = A_{init}$$

$$\frac{dA}{dt} = \frac{A(p) - A}{\tau}$$

For both settings of **Opening dynamics**, the flow rate through the valve is:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$A(p) = \begin{cases} A_{leak} & \text{for } p \leq p_{crack} \\ A_{leak} + k \cdot (p - p_{crack}) & \text{for } p_{crack} < p < p_{max} \\ A_{max} & \text{for } p \geq p_{max} \end{cases}$$

$$k = \frac{A_{max} - A_{leak}}{p_{max} - p_{crack}}$$

$$\Delta p = p_A - p_B,$$

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where:

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A$	Instantaneous orifice passage area
$A(p)$	Pressure-dependent orifice passage area
$A_{init}$	Initial open area of the valve
$A_{max}$	Fully open valve passage area
$A_{leak}$	Closed valve leakage area
$p_{crack}$	Valve cracking pressure
$p_{max}$	Pressure needed to fully open the valve
$p_{cr}$	Minimum pressure for turbulent flow
$Re_{cr}$	Critical Reynolds number



$D_H$	Instantaneous orifice hydraulic diameter
$\rho$	Fluid density
$\nu$	Fluid kinematic viscosity
$\tau$	Time constant for the first order response of the valve opening
$t$	Time

The block positive direction is from port **A** to port **B**. This means that the flow rate is positive if it flows from **A** to **B**, and the pressure differential is  $\Delta p = p_A - p_B$ .

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- The valve opening is linearly proportional to the pressure differential.
- The block does not consider loading on the valve, such as inertia, friction, spring, and so on.

## Ports

### Conserving

#### A – Valve inlet

hydraulic

Hydraulic conserving port associated with the valve inlet.

#### B – Valve outlet

hydraulic

Hydraulic conserving port associated with the valve outlet.

## Parameters

### Maximum passage area – Valve passage maximum cross-sectional area

$1e-4 \text{ m}^2$  (default) | positive scalar

Maximum cross-sectional area of the valve passage.

### Cracking pressure – Pressure level at which orifice of valve starts to open

$0.3e5 \text{ Pa}$  (default) | positive scalar

Pressure level at which the orifice of the valve starts to open.

**Maximum opening pressure — Pressure differential across valve needed to fully open valve**

1.2e5 Pa (default) | positive scalar

Pressure differential across the valve needed to fully open the valve. This value must be higher than the cracking pressure.

**Flow discharge coefficient — Valve capacity characterization**

0.7 (default) | positive scalar

Semi-empirical parameter for the valve capacity characterization. This value depends on the geometrical properties of the orifice. Manufacturer data sheets and textbooks typically provide this value.

**Leakage area — Total area of possible leaks in the completely closed valve**1e-12 m<sup>2</sup> (default) | positive scalar

Total area of possible leaks in the completely closed valve. This parameter maintains the numerical integrity of the circuit by preventing a portion of the system from being isolated when the valve is completely closed.

**Laminar transition specification — How block transitions between laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

How the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime takes place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio — Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | scalar between 0 and 1

Pressure ratio at which the flow transitions between laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Laminar transition specification** to **Pressure ratio**.

**Critical Reynolds number — Maximum Reynolds number for laminar flow**

12 (default) | positive scalar

Maximum Reynolds number for laminar flow. This value depends on the orifice geometrical profile. You can find recommendations for this value in hydraulics textbooks. The default value, 12, corresponds to a round orifice in thin material with sharp edges.

**Dependencies**

To enable this parameter, set **Laminar transition specification** to **Reynolds number**.

**Opening dynamics — Whether to include valve opening dynamics**

Do not include valve opening dynamics (default) | Include valve opening dynamics

Whether to include the valve opening dynamics. Select one of the following options:

- **Do not include valve opening dynamics** — The valve sets its orifice passage area directly as a function of pressure. If the area changes instantaneously, so does the flow equation.
- **Include valve opening dynamics** — This setting provides continuous behavior that is more physically realistic by adding a first-order lag when the valve opens and closes. Use this option in hydraulic simulations with the local solver for real-time simulation. This option is also helpful if you are interested in valve opening dynamics in variable step simulations.

#### **Opening time constant — Time constant for first-order response of valve opening**

0.1 s (default) | positive scalar

Time constant for the first-order response of the valve opening.

##### **Dependencies**

To enable this parameter, set **Opening dynamics** to Include valve opening dynamics.

#### **Initial area — Initial opening area of valve**

1e-12 m<sup>2</sup> (default) | positive scalar

Initial opening area of the valve. This value must be greater than the **Leakage area** parameter and less than the **Maximum passage area** parameter.

##### **Dependencies**

To enable this parameter, set **Opening dynamics** to Include valve opening dynamics.

## **Version History**

Introduced in R2006a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Pilot-Operated Check Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Check Valve (IL)

Check valve in an isothermal system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



### Description

The Check Valve (IL) block represents a check valve with free flow from port **A** to port **B** and restricted flow from port **B** to port **A**. When the pressure at port **B** meets or exceeds the set pressure threshold, the valve begins to open.

You can model valve opening either linearly or by tabulated data, and you can include faults by setting **Enable faults** to On.

### Opening Parameterization

When **Opening parameterization** is set to Linear - Area vs. pressure, the valve open area is linearly related to the opening pressure differential.

### Opening Pressure

There are two options for valve control:

- When **Opening pressure differential** is set to Pressure differential, the control pressure is the pressure differential between ports **A** and **B**. The valve begins to open when  $P_{\text{control}}$  meets or exceeds the **Cracking pressure differential**.
- When **Opening pressure differential** is set to Pressure at port A, the control pressure is the pressure difference between port **A** and atmospheric pressure. When  $P_{\text{control}}$  meets or exceeds the **Cracking pressure (gauge)**, the valve begins to open.

### Opening Area and Pressure

The linear parameterization of the valve area is

$$A_{\text{valve}} = \hat{p}(A_{\text{max}} - A_{\text{leak}}) + A_{\text{leak}},$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{\text{control}} - p_{\text{cracking}}}{p_{\text{max}} - p_{\text{cracking}}}.$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{\text{cracking}}$  and  $p_{\text{max}}$ . For more information, see “Numerical Smoothing”.

When you set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure,  $A_{valve}$  is the linearly interpolated value of the **Opening area vector** parameter versus **Pressure differential vector** parameter curve for a simulated pressure differential.

### Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left(1 - \left(\frac{A_{valve}}{A_{port}}\right)^2\right) [\Delta p^2 + \Delta p_{crit}^2]^{1/4}}}, \Delta p$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{valve}$  is the instantaneous valve open area.
- $A_{port}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

### Tabulated Volumetric Flow Rate Parameterization

When **Opening parameterization** is set to Tabulated data - Volumetric flow rate vs. pressure, the valve opens according to the user-provided tabulated data of volumetric flow rate and pressure differential between ports **A** and **B**.

Within the limits of the tabulated data, the mass flow rate is calculated as:

$$\dot{m} = \bar{\rho} \dot{V},$$

where:

- $\dot{V}$  is the volumetric flow rate.
- $\bar{\rho}$  is the average fluid density.

When the simulation pressure falls below the first element of the **Pressure drop vector**,  $\Delta p_{TLU}(1)$ , the mass flow rate is calculated as:

$$\dot{m} = K_{Leak} \bar{\rho} \sqrt{\Delta p}$$

$$K_{Leak} = \frac{V_{TLU}(1)}{\sqrt{|\Delta p_{TLU}(1)|}}$$

where  $V_{TLU}(1)$  is the first element of the **Volumetric flow rate vector**.

When the simulation pressure rises above the last element of the **Pressure drop vector**,  $\Delta p_{TLU}(end)$ , the mass flow rate is calculated as:

$$\dot{m} = K_{Max} \bar{\rho} \sqrt{\Delta p}$$

$$K_{Max} = \frac{V_{TLU}(end)}{\sqrt{|\Delta p_{TLU}(end)|}}$$

where  $V_{TLU}(end)$  is the last element of the **Volumetric flow rate vector**.

### Opening Dynamics

The linear parameterization supports valve opening and closing dynamics. If opening dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{control}$  becomes the dynamic control pressure,  $p_{dyn}$ ; otherwise,  $p_{control}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}$$

By default, **Opening dynamics** is set to Off.

### Faults

When faults are enabled, the valve open area becomes stuck at a specified value in response to one or both of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **T**.

Three fault options are available in the **Opening area when faulted** parameter:

- Closed
- Open
- Maintain at last value

Once triggered, the valve remains at the faulted area for the rest of the simulation. You can set the block to issue a fault report as a warning or error message in the Simulink Diagnostic Viewer with the **Reporting when fault occurs** parameter.

### Faulting in the Linear Parameterization

In the linear parameterization, the fault options are defined by the valve area:

- Closed — The valve area freezes at the **Leakage area**.
- Open — The valve area freezes at the **Maximum opening area**.
- Maintain at last value — The valve freezes at the open area when the trigger occurs.

### Faulting in the Tabulated Data Parameterization

In the tabulated parameterization, the fault options are defined by the mass flow rate through the valve:

- Closed — The valve freezes at the mass flow rate associated with the first elements of the **Volumetric flow rate vector** and the **Pressure drop vector**:

$$\dot{m} = K_{Leak} \bar{\rho} \sqrt{\Delta p}.$$

- Open — The valve freezes at the mass flow rate associated with the last elements of the **Volumetric flow rate vector** and the **Pressure drop vector**:

$$\dot{m} = K_{Max} \bar{\rho} \sqrt{\Delta p}$$

- Maintain at last value — The valve freezes at the mass flow rate and pressure differential when the trigger occurs:

$$\dot{m} = K_{Last} \bar{\rho} \sqrt{\Delta p},$$

where

$$K_{Last} = \frac{|\dot{m}|}{\bar{\rho} \sqrt{|\Delta p|}}.$$

### Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see “List of Pre-Parameterized Components”.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Entry point to the valve.

#### **B – Liquid port**

isothermal liquid

Exit point to the valve.

### Input

#### **T – External fault trigger**

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

### Dependencies

This port is visible when **Enable faults** is set to On and **Enable external fault trigger** is set to Fault when  $T \geq 0.5$ .

## Parameters

### Parameters

#### **Opening parameterization – Method of calculating valve opening**

Linear - Area vs. pressure (default) | Tabulated data - Area vs. pressure |  
Tabulated data - Volumetric flow rate vs. pressure

Method of calculating valve opening.

- **Linear - Area vs. pressure:** The valve opening area corresponds linearly to the valve pressure.
- **Tabulated data - Area vs. pressure:** The valve mass flow rate is determined from a table of area values with respect to pressure differential.
- **Tabulated data - Volumetric flow rate vs. pressure:** The valve mass flow rate is determined from a table of volumetric flow rate values with respect to pressure differential.

#### **Opening pressure specification – Pressure differential used for valve control**

Pressure differential (default) | Pressure at port A

Specifies the control pressure differential. The **Pressure differential** option refers to the pressure difference between ports **A** and **B**. The **Pressure at port A** option refers to the pressure difference between port **A** and atmospheric pressure.



**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Cracking pressure differential – Threshold pressure**

0.01 MPa (default) | positive scalar

Pressure beyond which the valve operation is triggered. This is the set pressure when the control pressure is the pressure differential between ports **A** and **B**.

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Pressure differential and **Opening parameterization** to Linear - Area vs. pressure.

**Cracking pressure (gauge) – Threshold pressure**

0.1 MPa (default) | positive scalar

Gauge pressure beyond which valve operation is triggered when the control pressure is the pressure differential between port **A** and atmospheric pressure.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure and **Opening pressure specification** to Pressure at port A.

**Maximum opening pressure differential – Valve differential pressure maximum**

0.1 MPa (default) | positive scalar

Maximum valve differential pressure. This parameter provides an upper limit to the pressure so that system pressures remain realistic.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure and **Opening pressure specification** to Pressure differential.

**Maximum opening pressure (gauge) – Valve pressure maximum**

0.2 MPa (default) | positive scalar

Maximum valve gauge pressure. This parameter provides an upper limit to the pressure so that system pressures remain realistic.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure and **Opening pressure specification** to Pressure at port A.

**Maximum opening area – Area of fully opened valve**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve in its fully open position.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Leakage area – Valve gap area when in fully closed position**1e-12 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in its fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Pressure differential vector – Differential pressure values for tabular parameterization**

[0.01 : 0.01 : 0.1] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Opening area vector** parameter. The elements are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set:

- **Set pressure control** to Constant.
- **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.
- **Opening pressure specification** to Pressure differential.

**Opening area vector – Valve opening areas for tabular parameterization**[1e-10, 1e-05, 2e-05, 3e-05, 4e-05, 5e-05, 6e-05, 7.5e-05, 8.5e-05, .0001] m<sup>2</sup> (default) | 1-by-n vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Pressure differential vector** parameter. The elements are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data - Area vs. pressure.

**Cross-sectional area at ports A and B – Area at valve entry or exit**inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. These areas are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

#### Critical Reynolds number — Upper Reynolds number limit for laminar flow

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

#### Smoothing factor — Numerical smoothing factor

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

#### Pressure recovery — Whether to account for pressure increase in area expansions

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

#### Opening dynamics — Whether to account for flow response to valve opening

Off (default) | On

Whether to account for transient effects to the fluid system due to opening the valve. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the flow response. The **Opening time constant** also impacts the modeled opening dynamics.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

#### Opening time constant — Valve opening time constant

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure and **Opening dynamics** to On.

**Volumetric flow rate vector – Vector of volumetric flow rate for tabulated data parameterization**

[.000358, .045, .11, .191, .284, .39, .505, .63, .764, .905] .\* 1e-3 m<sup>3</sup>/s  
(default) | 1-by-*n* vector

Vector of volumetric flow rate values for the tabular parameterization of valve opening. This vector must have the same number of elements as the **Pressure drop vector** parameter. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Faults****Enable faults – Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Opening area when faulted** parameter.

**Opening area when faulted – Set faulted characteristics**

Closed (default) | Open | Maintain at last value

Sets the faulted valve area or mass flow rate. You can choose for the valve to seize at the fully closed or fully open position, or at the conditions when faulting is triggered. This parameter sets the area when **Opening parameterization** is set to Linear - Area vs. pressure and the mass flow rate when **Opening parameterization** is set to Tabulated data.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Enable external fault trigger – External trigger option**

Off (default) | Fault when T >= 0.5

Enables port **T**. A physical signal at port **T** that is greater than 0.5 triggers faulting.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Enable temporal fault trigger – Temporal trigger option**

Off (default) | On

Enables fault triggering at a specified time. When the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Opening area when faulted** parameter.

### Dependencies

To enable this parameter, set **Enable faults** to On.

### Simulation time for fault event — Time at which faulting is triggered

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Opening area when faulted** parameter.

### Dependencies

To enable this parameter, set **Enable faults** to On and **Enable temporal fault trigger** to On.

### Reporting when fault occurs — Fault condition report

None (default) | Warning | Error

Reporting preference for the fault condition. When reporting is set to **Warning** or **Error**, a message is displayed in the Simulink Diagnostic Viewer. When **Error** is selected, the simulation will stop if faulting occurs.

### Dependencies

To enable this parameter, set **Enable faults** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Pilot-Operated Check Valve (IL) | Pressure Relief Valve (IL) | Counterbalance Valve (IL) | Pressure Compensator Valve (IL)

## Check Valve (G)

Check valve in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Directional Control Valves



### Description

The Check Valve (G) block represents an orifice with a unidirectional opening mechanism that prevents unwanted backflow. The opening mechanism responds to pressure, and opens the orifice when the pressure gradient falls from the inlet at port **A** to the outlet at port **B**. Check valves protect components upstream against pressure surges, temperature spikes, and chemical contamination stemming from points downstream.

The valve begins opening at the cracking pressure and continues opening until the end of the pressure regulation range. The cracking pressure is the initial resistance, due to friction or spring forces, that the valve must overcome to crack open. Below this threshold, the valve is closed and only leakage flow can pass. Past the end of the pressure regulation range, the valve is fully open and the flow at the maximum value is determined by the instantaneous pressure conditions.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

### Control and Other Pressures

The pressure to which the valve responds is the control pressure. By default, the control pressure is the drop from inlet to outlet. This setting ensures that the valve closes if the direction of flow should reverse.

You can also specify the control pressure as the gauge pressure at the inlet. Use this setting if you know that the inlet will always be at a higher pressure than the outlet. For example, when the inlet connects to a pressure source, such as a pump.

You can select the control pressure by setting the **Opening pressure specification** parameter to Pressure difference of port A relative to port B or Gauge pressure at port A.

#### Pressure difference of port A relative to port B

When the **Opening pressure specification** parameter is Pressure difference of port A relative to port B:

- The control pressure is:

$$P_{Ch} = P_A - P_B,$$

where  $P_A$  is the absolute pressure at port **A** and  $P_B$  is the absolute pressure at port **B**.

- The cracking pressure,  $P_{Crk}$ , is the value of the **Cracking pressure differential** parameter.
- The maximum pressure of the valve,  $P_{Max}$ , where the valve is fully open, is the value of the **Maximum opening pressure differential** parameter.

### Gauge pressure at port A

When the **Opening pressure specification** parameter is Gauge pressure at port A:

- The control pressure is

$$P_{Ctrl} = P_A - P_{Atm},$$

where  $P_{Atm}$  is the atmospheric pressure specified in the Gas Properties (G) block of the model.

- The cracking pressure,  $P_{Crk}$ , is the value of the **Cracking pressure (gauge)** parameter.
- The maximum pressure of the valve,  $P_{Max}$ , where the valve is fully open, is the value of the **Maximum opening pressure (gauge)** parameter.

### Fraction of Valve Opening

The degree to which the control pressure exceeds the cracking pressure determines how much the valve opens. The fraction of valve opening is

$$\hat{P} = \frac{P_{Ctrl} - P_{Crk}}{P_{Max} - P_{Crk}},$$

where:

- $P_{Ctrl}$  is the control pressure.
- $P_{Crk}$  is the cracking pressure.
- $P_{Max}$  is the maximum opening pressure.

The fraction is normalized so that it is 0 in the fully closed valve and 1 in the fully open valve. If the calculation returns a value outside of these bounds, the block saturates the value to the nearest of the two limits.

### Numerical Smoothing

When the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized control pressure,  $\hat{P}$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.

- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parametrization.

The block scales the specified flow capacity by the fraction of valve opening. As the fraction of valve opening rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.

### Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3 p_{in} F_\gamma x_T},$$

where:

- $F_\gamma$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3 F_\gamma x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_\gamma x_T$ , the orifice becomes choked and the block switches to the equation



$$\dot{m} = \frac{2}{3} C_v N_6 \sqrt{F_y x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865 C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{p_{out} - B_{crit}}{p_{in} (1 - B_{crit})} \right)^{2m} \right],$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C \rho_{ref} \sqrt{\frac{T_{ref}}{T_{avg}}} \left[ 1 - \left( \frac{B_{lam} - B_{crit}}{1 - B_{crit}} \right)^{2m} \right] \left( \frac{p_{in} - p_{out}}{1 - B_{lam}} \right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left( \frac{p_{out}}{p_{in}} \right)^{\frac{\gamma-1}{\gamma}}}{1 - \left( \frac{S_R}{S} \right)^2 \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}}} \right]},$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \left[ \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}} \right] \left( \frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}} \right)}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Assumptions and Limitations

- The Sonic conductance setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.

- The equation for the `Orifice area` parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Conserving

#### A – Valve entrance

gas

Gas conserving port associated with the opening through which the flow must enter the valve.

#### B – Valve entrance

gas

Gas conserving port associated with the opening through which the flow must exit the valve.

## Parameters

### Opening pressure specification – Choice of pressure measurement to use as valve control signal

Pressure difference of port A relative to port B (default) | Gauge pressure at port A

Choice of pressure measurement to use as valve control signal. The block uses this setting to determine when the valve should begin to open. In the default setting, `Pressure difference of port A relative to port B`, the opening pressure of the valve is expressed as a pressure drop from inlet to outlet. In the alternative setting, `Gauge pressure at port A`, it is expressed as a gauge pressure.

### Cracking pressure differential – Pressure drop required to open valve

0.01 MPa (default) | positive scalar

Minimum pressure drop, from inlet to outlet, required to open the valve. This value marks the beginning of the pressure differential range of the valve, over which it progressively opens to allow for increased flow.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to `Pressure difference of port A relative to port B`.

### Maximum opening pressure differential – Pressure drop at which valve is fully open

0.02 MPa (default) | positive scalar

Pressure drop, from inlet to outlet, at which the valve is fully open. This value marks the end of the pressure differential range of the valve, over which the same progressively opens to allow for increased flow.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to `Pressure difference of port A relative to port B`.

**Cracking pressure (gauge) — Minimum pressure at inlet required to open valve**

0.01 MPa (default) | positive scalar

Minimum gauge pressure at the inlet (port **A**) required to open the valve. This value marks the beginning of the pressure range of the valve, over which the same progressively opens to allow for increased flow.

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A.

**Maximum opening pressure (gauge) — Maximum pressure at inlet**

0.02 MPa (default) | positive scalar

Maximum pressure at inlet port **A**, at which the valve is fully open. This value marks the end of the pressure differential range of the valve, over which the same progressively opens to allow for increased flow.

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A.

**Valve parameterization — Parameterization used to specify flow characteristics of orifice**

Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- Cv flow coefficient — The flow coefficient  $C_v$  determines the block parameterization.
- Kv flow coefficient — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- Sonic conductance — The sonic conductance of the resistive element at steady state determines the block parameterization.
- Orifice area — The size of the flow restriction determines the block parameterization.

**Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient.

**xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Maximum Kv flow coefficient – Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Maximum value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient.

**Maximum sonic conductance – Sonic conductance corresponding to maximally open component**

12  $\text{l}/(\text{bar}\cdot\text{s})$  (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Critical pressure ratio – Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Subsonic index – Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference temperature – ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference density – ISO 8778 reference density**

1.185  $\text{kg}/\text{m}^3$  (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**Maximum orifice area — Flow area corresponding to maximally open component**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Leakage flow fraction — Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio — Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B — Flow area at gas ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

**Introduced in R2018b****Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.
- The **Pressure control specification** parameter has been renamed to **Opening pressure specification**. The options for this parameter have been renamed to **Pressure difference of port A relative to port B** and **Gauge pressure at port A**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Orifice (G) | Pilot-Operated Check Valve (G)

## Check Valve (TL)

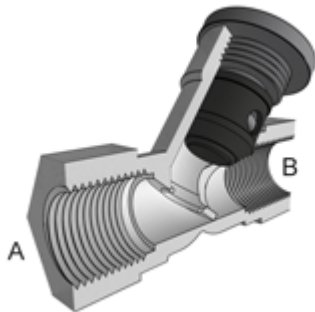
Valve for the prevention of flow aimed counter to its intended direction

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices /  
Directional Control Valves



### Description

The Check Valve (TL) block models the opening characteristics of a proportional valve that is forced shut when the pressure difference between its ports is reversed (or, more precisely, dropped below a threshold known as the *cracking pressure*). Check valves are common in backflow prevention devices, such as those used in public water supply networks, where contaminated water downstream of a water main must not be allowed to return upstream. No specific valve shutoff mechanism—whether ball, disc, diaphragm, or other—is assumed in the block. The allowed direction of flow is always from port **A** to port **B**.



### Y-Shaped Check Valve with Piston-Type Control Member Partially Retracted

The valve cracks open when the pressure drop across it rises above the cracking pressure specified in the block. The opening area increases linearly with pressure, save for two small pressure intervals near the fully open and fully closed positions (over which nonlinear smoothing is applied in order to remove numerical discontinuities). When the pressure drop reaches the maximum value specified in the block, the valve is fully open and its opening area no longer increases with pressure. The flow rate through the valve is never truly zero as a small leakage area remains when the pressure falls below the cracking pressure.

### Valve Opening Area

The (smoothed) valve opening area is first computed as a linear function of pressure, either that at the valve entrance (port **A**) or the drop between those at the entrance and at the outlet (port **B**). Which of these pressures—termed control pressures—features in the area calculations depends on the setting of the **Pressure specification method** block parameter:



$$p_{\text{Control}} = \begin{cases} p_A, & \text{Pressure at port A method} \\ p_A - p_B, & \text{Pressure differential method} \end{cases}$$

where  $p$  is pressure; the subscript **Control** indicates the value to be used in determining the opening area of the valve. Subscripts **A** and **B** denote the thermal liquid ports at which the pressures are obtained. The pressures at the ports are always defined as absolute pressures. The cracking pressure, at which the opening area is at a minimum, is similarly defined:

$$p_{\text{Crack}} = \begin{cases} p_{\text{Crack,G}} + p_{\text{Atm}}, & \text{Pressure at port A method} \\ \Delta p_{\text{Crack}}, & \text{Pressure differential method} \end{cases}$$

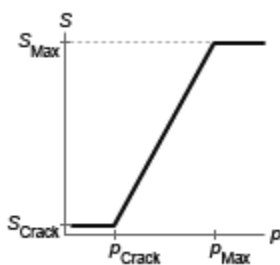
where the subscript **Crack** indicates a valve just cracking open, subscript **G** a gauge value, and subscript **Atm** the standard atmospheric value. The value of  $p_{\text{Crack,G}}$  is obtained from the **Cracking pressure (gauge)** block parameter; that of  $\Delta p_{\text{Crack}}$  is obtained from the **Cracking pressure differential** block parameter. The maximum pressure, at which the opening area is at its largest, is:

$$p_{\text{Max}} = \begin{cases} p_{\text{Max,G}} + p_{\text{Atm}}, & \text{Pressure at port A method} \\ \Delta p_{\text{Max}}, & \text{Pressure differential method} \end{cases}$$

where subscript **Max** denotes a maximum pressure (obtained as gauge). The value of  $p_{\text{Max,G}}$  is obtained from the **Maximum opening pressure (gauge)** block parameter; that of  $\Delta p_{\text{Max}}$  is obtained from the **Maximum opening pressure differential** block parameter. The control, cracking, and maximum pressures give for the linear form of the valve opening area:

$$S_{\text{Lin}} = \frac{S_{\text{Max}} - S_{\text{Crack}}}{p_{\text{Max}} - p_{\text{Crack}}} (p_{\text{Ctl}} - p_{\text{Crack}}) + S_{\text{Crack}}$$

where  $S$  denotes the (linear) opening area. The opening area at cracking is equal to the small value specified in the **Leakage area** block parameter. The primary purpose of this parameter is to ensure the numerical robustness of the model by ensuring that no portion of a thermal liquid network becomes completely isolated during simulation.



### Valve opening area as a linear function of pressure

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{\text{Crack}}$  and  $p_{\text{Max}}$ . For more information, see “Numerical Smoothing”.

### Leakage Area

The primary purpose of the leakage area of a closed valve is to ensure that at no time does a portion of the hydraulic network become isolated from the remainder of the model. Such isolated portions

reduce the numerical robustness of the model and can slow down simulation or cause it to fail. Leakage is generally present in minuscule amounts in real valves but in a model its exact value is less important than it being a small number greater than zero. The leakage area is obtained from the block parameter of the same name.

### Mass Balance

The volume of fluid inside the valve, and therefore the mass of the same, is assumed to be very small and it is, for modeling purposes, ignored. As a result, no amount of fluid can accumulate there. By the principle of conservation of mass, the mass flow rate into the valve through one port must therefore equal that out of the valve through the other port:

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate *into* the valve through one of the ports (**A** or **B**).

### Momentum Balance

The causes of those pressure losses incurred in the passages of the valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. This effect is captured in the block by the discharge coefficient, a measure of the mass flow rate through the valve relative to the theoretical value that it would have in an ideal valve. Expressing the momentum balance in the valve in terms of the pressure drop induced in the flow:

$$p_A - p_B = \frac{\dot{m}_{\text{Avg}} \sqrt{\dot{m}_{\text{Avg}}^2 + \dot{m}_{\text{Crit}}^2}}{2\rho_{\text{Avg}} C_D S_{\text{Smooth}}^2} \left[ 1 - \left( \frac{S_{\text{Smooth}}}{S_{\text{Lin}}} \right)^2 \right] \xi_p,$$

where  $C_D$  is the discharge coefficient, and  $\xi_p$  is the pressure drop ratio—a measure of the extent to which the pressure recovery at the outlet contributes to the total pressure drop of the valve. The subscript Avg denotes an average of the values at the thermal liquid ports. The critical mass flow rate  $\dot{m}_{\text{Crit}}$  is calculated from the critical Reynolds number—that at which the flow in the orifice is assumed to transition from laminar to turbulent:

$$\dot{m}_{\text{Crit}} = \text{Re}_{\text{Crit}} \mu_{\text{Avg}} \sqrt{\frac{\pi}{4} S_{\text{Lin}}},$$

where  $\mu$  denotes dynamic viscosity. The pressure drop ratio is calculated as:

$$\xi_p = \frac{\sqrt{1 - \left( \frac{S_{\text{Smooth}}}{S_{\text{Lin}}} \right)^2 (1 - C_D^2)} - C_D \frac{S_{\text{Smooth}}}{S_{\text{Lin}}}}{\sqrt{1 - \left( \frac{S_{\text{Smooth}}}{S_{\text{Lin}}} \right)^2 (1 - C_D^2)} + C_D \frac{S_{\text{Smooth}}}{S_{\text{Lin}}}}.$$

### Energy Balance

The valve is modeled as an adiabatic component. No heat exchange can occur between the fluid and the wall of the valve. No work is done on or by the fluid as it traverses the valve. With these assumptions, energy can enter and exit the valve by advection only, through ports **A** and **B**. By the principle of conservation of energy then, the sum of the energy flows through the ports must always equal zero:

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is defined as the energy flow rate *into* the valve through one of the ports (**A** or **B**).

## Ports

### Conserving

#### **A – Valve inlet**

thermal liquid

Opening through which the flow can enter the valve.

#### **B – Valve outlet**

thermal liquid

Opening through which the flow can exit the valve.

## Parameters

### **Pressure control specification – Choice of pressure to use in the block calculations**

Pressure at port A (default) | Pressure differential

Choice of pressure to use in the block calculations. The default setting corresponds to the gauge pressure at the valve inlet (port **A**). The alternative setting corresponds to the pressure differential from inlet (**A**) to outlet (**B**).

### **Cracking pressure (gauge) – Gauge pressure at which the valve begins to open**

0.1 MPa (default) | positive scalar in units of pressure

Gauge pressure at port **A** at which the valve begins to open. The valve opening area is saturated at the value of the **Leakage area** block parameter when the pressure at port **A** is at or below the value specified here.

#### **Dependencies**

This parameter is active when the **Pressure control specification** block parameter is set to Pressure at port A.

### **Maximum opening pressure (gauge) – Gauge pressure at which the valve is fully open**

0.2 MPa (default) | positive scalar in units of pressure

Gauge pressure at port **A** at which the valve is fully open. The valve opening area is saturated at the value specified in the **Maximum opening area** block parameter when the pressure at port **A** is at or above the value specified here.

#### **Dependencies**

This parameter is active when the **Pressure control specification** block parameter is set to Pressure at port A.

### **Cracking pressure differential – Pressure differential from port A to port B at which the valve begins to open**

0.1 MPa (default) | positive scalar in units of pressure

Pressure differential from port A to port B at which the valve begins to open. The valve opening area is saturated at the value of the **Leakage area** block parameter when the pressure differential is at or below the value specified here.

**Dependencies**

This parameter is active when the **Pressure control specification** block parameter is set to Pressure differential.

**Maximum opening pressure differential — Pressure differential from port A to port B at which the valve is fully open**

0.2 MPa (default) | positive scalar in units of pressure

Pressure differential from port A to port B at which the valve is fully open. The valve opening area is saturated at the value specified in the **Maximum opening area** block parameter when the pressure differential is at or above the value specified here.

**Dependencies**

This parameter is active when the **Pressure control specification** block parameter is set to Pressure differential.

**Maximum opening area — Opening area of the valve in the fully open position**

1e-4 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully open position. The valve is fully open if the pressure drop from port **A** to port **B** is equal to or greater than that given by the **Maximum opening pressure** block parameter.

**Leakage area — Opening area of the valve in the maximally closed position**

1e-10 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully closed position, when only internal leakage between its ports remains. This parameter serves primarily to ensure that closure of the valve does not cause portions of the thermal liquid network to become isolated. The exact value specified here is less important than its being a small number greater than zero.

**Smoothing factor — Measure of the amount of smoothing to apply to the opening area function**

0.01 (default) | positive unitless scalar

Measure of the amount of smoothing to apply to the opening area function. This parameter determines the widths of the regions to be smoothed, one being at the fully open position, the other at the fully closed position. The smoothing superposes on the linear opening area function two nonlinear segments, one for each region of smoothing. The greater the value specified, the greater the smoothing and the broader the nonlinear segments.

**Cross-sectional area at ports A and B — Flow area at the thermal liquid ports**

0.01 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the flow path at each port. The ports are assumed to be equal in size. The flow area specified here should match those of the inlets of those components to which the orifice connects.

**Discharge coefficient — Empirical factor defined as the ratio of actual to ideal mass flow rates**

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

**Variables**

**Mass flow rate into port A — Initial state target for the mass flow rate of the valve**

cleared (default) | checked

Desired mass flow rate into the valve through port A at the start of simulation. This parameter serves as an initial state target, a guide used by Simscape in assembling the initial configuration of the model. How closely the target is met depends on the constraints imposed by the remainder of the model and on the priority level specified.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Orifice (TL) | 2-Way Directional Valve (TL) | 3-Way Directional Valve (TL) | 4-Way 3-Position Directional Valve (TL)

## Check Valve (2P)

Check valve in a two-phase fluid network

**Library:** Simscape / Fluids / Two-Phase Fluid / Valves & Orifices / Directional Control Valves



### Description

The Check Valve (2P) block models a directional control check valve in a two-phase fluid network. The valve maintains the fluid pressure by opening above a specified pressure and allowing flow from port **A** to port **B**, but not in the reverse direction. The pressure differential that opens the valve is specified in the **Opening pressure specification** parameter. This value can be either the pressure difference between ports **A** and **B** or the gauge pressure at port **A**.

Fluid properties inside the valve are calculated from inlet conditions. There is no heat exchange between the fluid and the environment, and therefore phase change inside the valve only occurs due to a pressure drop or a change propagated from another part of the model.

A number of block parameters are based on nominal operating conditions, which correspond to the valve rated performance, such as a specification on a manufacturer datasheet.

### Directional Control

The valve opens when the pressure in the valve,  $p_{control}$ , exceeds the cracking pressure,  $p_{crack}$ . The valve is fully open when the control pressure reaches the valve maximum pressure,  $p_{max}$ . The opening fraction of the valve,  $\lambda$ , is expressed as:

$$\lambda = (1 - f_{leak}) \frac{(p_{control} - p_{crack})}{(p_{max} - p_{crack})} + f_{leak},$$

where:

- $f_{leak}$  is the **Closed valve leakage as a fraction of nominal flow**.
- $p_{control}$  is the control pressure, which depends on the **Opening pressure specification** parameter.

When you set **Opening pressure specification** to Pressure differential, the control pressure is  $p_A - p_B$ .

When you set **Opening pressure specification** to Gauge pressure at port A, the control pressure is the difference between the pressure at port **A** and atmospheric pressure.

The cracking pressure and maximum pressure are specified as either a differential value or a gauge value, depending on the setting of the **Opening pressure specification**. If the control pressure exceeds the maximum pressure, the valve opening fraction is 1.

The mass flow rate depends on the pressure differential, and therefore the open area of the valve. The block calculates this as:

$$\dot{m}_A = \lambda \dot{m}_{nom} \left[ \sqrt{\frac{v_{nom}}{2\Delta p_{nom}}} \right] \sqrt{\frac{2}{v_{in} (\Delta p^2 + \Delta p_{lam}^2)^{0.25}}},$$

where:

- $\Delta p$  is the pressure drop over the valve,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure transition threshold between laminar and turbulent flow, which is calculated from the **Laminar flow pressure ratio**,  $B_{lam}$ :

$$\Delta p_{lam} = \frac{(p_A + p_B)}{2}(1 - B_{lam}).$$

- $\dot{m}_{nom}$  is the **Nominal mass flow rate at maximum valve opening**.
- $\Delta p_{nom}$  is the **Nominal pressure drop rate at maximum valve opening**.
- $v_{nom}$  is the nominal inlet specific volume. This value is determined from the fluid properties tabulated data based on the **Nominal inlet specific enthalpy** and **Nominal inlet pressure** parameters.
- $v_{in}$  is the inlet specific volume.

### Fluid Specific Volume Dynamics

When the fluid at the valve inlet is a liquid-vapor mixture, the block calculates the specific volume as:

$$v_{in} = (1 - x_{dyn})v_{liq} + x_{dyn}v_{vap},$$

where:

- $x_{dyn}$  is the inlet vapor quality. The block applies a first-order lag to the inlet vapor quality of the mixture.
- $v_{liq}$  is the liquid specific volume of the fluid.
- $v_{vap}$  is the vapor specific volume of the fluid.

If the inlet fluid is liquid or vapor,  $v_{in}$  is the respective liquid or vapor specific volume.

### Vapor Quality Lag

If the inlet vapor quality is a liquid-vapor mixture, the block applied a first-order time lag:

$$\frac{dx_{dyn}}{dt} = \frac{x_{in} - x_{dyn}}{\tau},$$

where:

- $x_{dyn}$  is the dynamic vapor quality.
- $x_{in}$  is the current inlet vapor quality.
- $\tau$  is the **Inlet phase change time constant**.

If the inlet fluid is a subcooled liquid or superheated vapor,  $x_{dyn}$  is equal to  $x_{in}$ .

### Mass Balance

Mass is conserved in the valve:

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

### Energy Balance

Energy is conserved in the valve:

$$\Phi_A + \Phi_B = 0,$$

where:

- $\Phi_A$  is the energy flow at port **A**.
- $\Phi_B$  is the energy flow at port **B**.

### Assumptions and Limitations

- The block does not model pressure recovery downstream of the valve.
- There is no heat exchange between the valve and the environment.
- The block does not model choked flow.

## Ports

### Conserving

#### **A – Fluid port**

two-phase fluid

Fluid entry port.

#### **B – Fluid port**

two-phase fluid

Fluid exit port.

## Parameters

### Opening pressure specification – Control pressure

Pressure differential (default) | Gauge pressure at port A

Control pressure specification:

- When set to Pressure differential, the valve opens when  $p_A - p_B$  exceeds the **Cracking pressure differential**.
- When set to Gauge pressure at port A, the valve opens when  $p_A - p_{atm}$  exceeds the **Cracking pressure (gauge)**.

### Cracking pressure differential – Cracking pressure

0.01 MPa (default) | positive scalar

Valve pressure threshold. When the control pressure,  $p_A - p_B$ , exceeds the opening pressure, the valve begins to open.



**Dependencies**

To enable this parameter, set **Opening pressure specification** to Pressure differential.

**Cracking pressure (gauge) – Cracking pressure**

0.1 MPa (default) | positive scalar

Valve pressure threshold. When the control pressure,  $p_A - p_{atm}$ , exceeds the opening pressure, the valve begins to open.

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A.

**Maximum opening pressure differential – Maximum valve operational pressure**

0.1 MPa (default) | positive scalar

Maximum valve operational pressure. The valve begins to open at the cracking pressure value, and is fully open at  $p_{max}$ .

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Pressure differential.

**Maximum opening pressure (gauge) – Pressure that fully opens the valve**

0.2 MPa (default) | positive scalar

Valve operational pressure at which the valve is fully open. The valve begins to open at the cracking pressure value, and is fully open at  $p_{max}$ .

**Dependencies**

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A.

**Nominal mass flow rate at maximum opening – Rated mass flow rate**

0.1 kg/s (default) | positive scalar

Mass flow rate through a fully open valve under typical, design, or rated conditions.

**Nominal pressure drop at maximum opening – Rated pressure drop**

0.001 MPa (default) | positive scalar

Pressure drop over a fully open valve under typical, design, or rated conditions.

**Nominal inlet condition specification – Method of determining inlet fluid state**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Method of determining inlet fluid state. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet pressure – Pressure of fluid entering valve**

0.101325 MPa (default) | positive scalar

Valve inlet pressure in typical, design, or rated conditions. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet temperature – Fluid temperature**

293.15 K (default) | positive scalar

Inlet fluid temperature in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Temperature.

**Nominal inlet vapor quality – Inlet vapor quality by mass fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet vapor quality of the mixture by mass fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor quality.

**Nominal inlet vapor void fraction – Inlet volume fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet mixture volume fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor void fraction.

**Nominal inlet specific enthalpy – Inlet fluid specific enthalpy**

1500 kJ/kg (default) | positive scalar

Inlet specific enthalpy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific enthalpy.

**Nominal inlet specific internal energy – Inlet specific internal energy**

1500 kJ/kg (default) | positive scalar

Inlet specific internal energy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific internal energy.

**Cross-sectional area at ports A and B – Valve port areas**

0.01 m<sup>2</sup> (default) | positive scalar

Area of the valve ports **A** and **B**.

**Closed valve leakage as a fraction of nominal flow — Fractional flow when valve is closed**

1e-6 (default) | positive scalar

Fractional flow rate through the valve when it is fully closed. This parameter contributes to numerical stability by maintaining continuity in the fluid network.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio — Laminar-turbulent transition pressure ratio**

0.999 (default) | positive scalar

Ratio of the valve outlet pressure to valve inlet pressure at which the fluid transitions between the laminar and turbulent regimes. The pressure loss corresponds to the mass flow rate linearly in laminar flows and quadratically in turbulent flows.

**Inlet phase change time constant — Lag for mixture specific volume**

0.1 s (default) | positive scalar

Time lag for liquid-vapor mixtures in computing the fluid specific volume. This parameter does not influence the specific volume when the inlet fluid is a fully supercooled liquid or fully superheated vapor.

## Version History

**Introduced in R2021a**

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Orifice (2P) | Pressure-Reducing Valve (2P) | Pressure Relief Valve (2P) | Thermostatic Expansion Valve (2P)

## Compressor (2P)

Two-phase fluid compressor in a thermodynamic cycle

**Library:** Simscape / Fluids / Two-Phase Fluid / Fluid Machines



### Description

The Compressor (2P) block represents a dynamic compressor, such as a centrifugal or axial compressor, in a two-phase fluid network. You can parameterize the block analytically based on the design point or by using a tabulated compressor map by setting **Parameterization** to **Analytical** or **Tabulated**, respectively. A positive rotation of port **R** relative to port **C** causes fluid to flow from port **A** to port **B**. Port **R** and port **C** are mechanical rotational conserving ports associated with the compressor shaft and casing, in that order.

The *surge margin* is the ratio between the surge pressure ratio at a given mass flow rate and the operating point pressure ratio minus 1. When you set **Parameterization** to **Tabulated**, the block outputs the surge margin at port **SM**.

The *design point* of the compressor is the design operational pressure ratio across and mass flow rate through the compressor during simulation. The compressor operating point and the point of maximum efficiency do not need to coincide.

The Compressor (2P) block assumes that superheated fluid enters the inlet. You can use the **Report when fluid is not fully vapor** parameter to choose what the block does when the fluid does not meet superheated conditions.

### Compressor Map

The map plots the isentropic efficiency of the compressor between the two extremes of choked flow and surge flow. The map plots the lines of constant corrected shaft speed between the two extremes of choked flow and surge flow. Each corrected speed line tells you how pressure ratio varies with corrected mass flow rate when the shaft spins at the corresponding corrected speed. The variable  $\beta$  indicates the relative position along the corrected speed lines between the two extremes. Choked flow corresponds to  $\beta = 0$ , and surge flow corresponds to  $\beta = 1$ . The map also plots contours of isentropic efficiency as a function of pressure ratio and corrected mass flow rate. This provides a relative indication of how much power the compressor needs to operate at various combinations of pressure ratio and corrected mass flow rate.

#### Corrected Mass Flow Rate

Due to the large changes in pressure and temperature inside a compressor, the compressor map plots performance in terms of a corrected mass flow rate. The corrected mass flow rate is adjusted from the inlet mass flow rate with a reference pressure and reference temperature:

$$\dot{m}_{corr} = \dot{m}_A \left( \frac{p_A}{p_{ref}} \sqrt{\frac{T_A}{T_{ref}}} \right),$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $T_A$  is the temperature at port **A**.
- $T_{ref}$  is the **Reference temperature for corrected flow**. When you set **Parameterization** to **Analytical**, this is the inlet temperature at the design operating condition.
- $\dot{m}_{corr}$  is the corrected mass flow rate.

When you set **Parameterization** to **Analytical**, the block uses the **Corrected mass flow rate at design point** parameter.

When you set **Parameterization** to **Tabulated**, the block uses the **Corrected mass flow rate table,  $\dot{m}(N,\beta)$**  parameter.

- $p_A$  is the pressure at port **A**.
- $p_{ref}$  is the **Reference pressure for corrected flow** parameter. When using the analytical parameterization, this is the inlet pressure at the design operating condition.

The block derives  $T_A$  from the specific internal energy,  $u_A$ , and specific pressure,  $p_A$ .

### Corrected Speed

The block also adjusts the shaft speed,  $\omega$ , according to the reference temperature, such that the corrected shaft speed is

$$\omega_{corr} = \frac{\omega}{\sqrt{\frac{T_A}{T_{ref}}}}$$

### Shaft Torque

The block calculates the shaft torque,  $\tau$ , as:

$$\tau = \frac{\dot{m}_A \Delta h_{total}}{\eta_m \omega}$$

where:

- $\Delta h_{total}$  is the change in specific total enthalpy.
- $\eta_m$  is the compressor **Mechanical efficiency**.
- $\omega$  is the relative shaft angular velocity,  $\omega_R - \omega_C$ .

The block relates the efficiency in the compressor map as

$$\Delta h_{total} = \frac{\Delta h_{isen}}{\eta_{isen}}$$

where

- $\Delta h_{isen}$  is the isentropic change in specific total enthalpy.
- $\eta_{isen}$  is the isentropic efficiency.

A threshold region when flow approaches zero ensures that no torque is generated when the flow rate is near zero or reversed.

### Analytical Parameterization

You can generate the compressor map analytically by setting **Parameterization** to **Analytical**. The block fits a model of the compressor map based on Greitzer et al, 2010 to the specified values for the **Corrected speed at design point**, **Pressure ratio at design point**, and **Corrected mass flow rate at design point** parameters. This method does not use  $\beta$  lines and the block does not report a surge margin.

#### Pressure Ratio

The block finds the pressure ratio at a given shaft speed and mass flow rate as:

$$\pi = 1 + (\pi_D - 1) \left[ \tilde{N}^{ab} + 2\tilde{N}k \ln \left( 1 - \frac{\tilde{m} - \tilde{N}^b}{k} \right) \right],$$

where:

- $\pi_D$  is the **Pressure ratio at design point** parameter.
- $\tilde{N}$  is the normalized corrected shaft speed,

$$\frac{N}{N_D},$$

where  $N_D$  is the **Corrected speed at design point** parameter.

- $\tilde{m}$  is the normalized corrected mass flow rate,

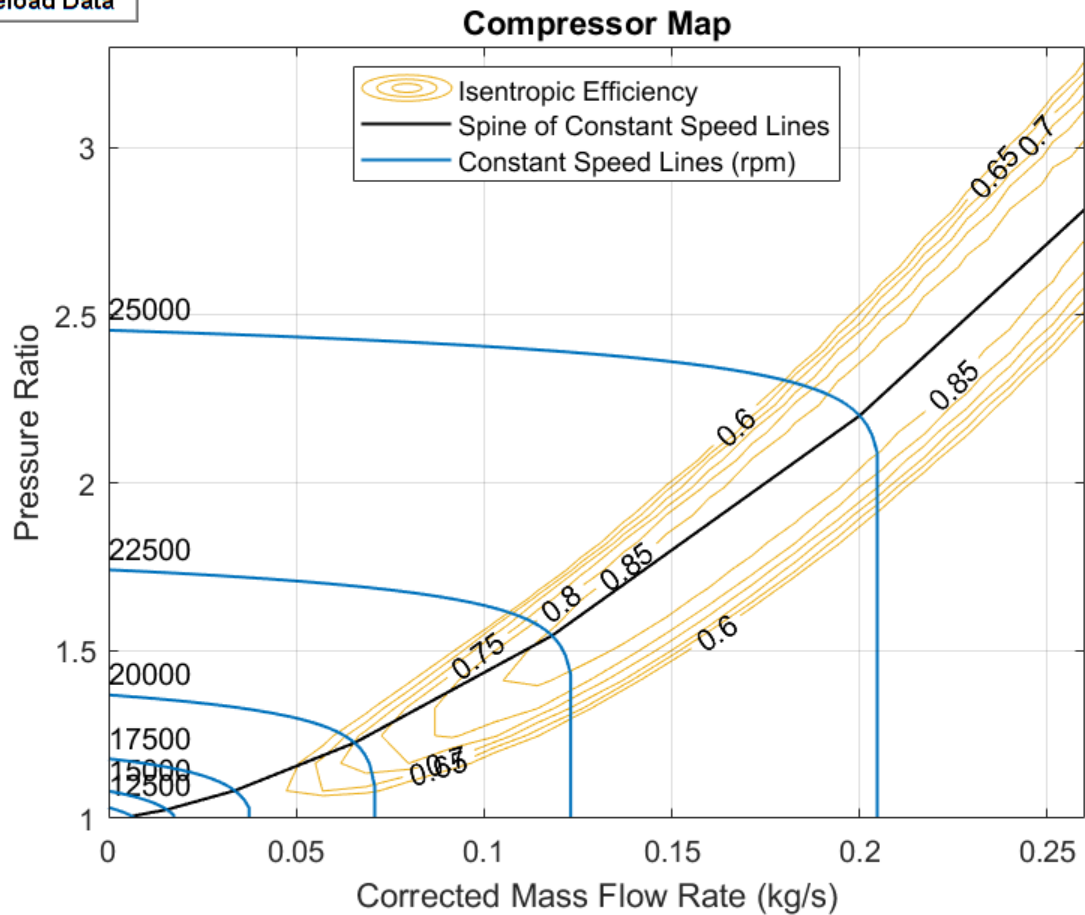
$$\frac{\dot{m}_{corr}}{\dot{m}_D},$$

where  $\dot{m}_D$  is the **Corrected mass flow rate at design point** parameter.

- $a$  is the **Spine shape, a** parameter.
- $b$  is the **Speed line spread, b** parameter.
- $k$  is the **Speed line roundness, k** parameter.

The *spine* refers to the black line where the isentropic efficiency contours start to bend. The map *speed lines* are the shaft constant-speed lines that intersect the spine perpendicularly.

Reload Data



### Analytical Parameterization Default Compressor Map

#### Isentropic Efficiency Parameterization

When you set **Efficiency specification** to Analytical, the block models variable compressor efficiency as:

$$\eta = \eta_0 \left( 1 - C \left| \frac{\tilde{p}}{\tilde{m}^{a+\Delta a-1}} - \tilde{m} \right|^c - D \left| \frac{\tilde{m}}{\tilde{m}_0} - 1 \right|^d \right),$$

where:

- $\eta_0$  is the **Maximum isentropic efficiency** parameter.
- $C$  is the **Efficiency contour gradient orthogonal to spine, C** parameter.
- $D$  is the **Efficiency contour gradient along spine, D** parameter.
- $c$  is the **Efficiency peak flatness orthogonal to spine, c** parameter.
- $d$  is the **Efficiency peak flatness along spine, d** parameter.
- $\tilde{p}$  is the normalized corrected pressure ratio,

$$\frac{\pi - 1}{\pi_D - 1},$$

where  $\pi_D$  is the **Corrected pressure ratio at design point** parameter.

- $\tilde{m}_0$  is the normalized corrected mass flow rate at which the compressor reaches its **Maximum isentropic efficiency** parameter.

You can adjust the efficiency variables for different performance characteristics.

Alternatively, you can choose a constant efficiency value by using the **Constant isentropic efficiency** parameter.

### **Tabulated Data Parameterization**

When you set **Parameterization** to **Tabulated**, the isentropic efficiency, pressure ratio, and corrected mass flow rate of the compressor are functions of the corrected speed,  $N$ , and the map index,  $\beta$ . The block uses linear interpolation between data points for the efficiency, pressure ratio, and corrected mass flow rate.

If  $\beta$  exceeds 1, compressor surge occurs, and the block assumes the pressure ratio remains at  $\beta = 1$ , while the mass flow rate continues to change. If the simulation conditions fall below  $\beta = 0$ , the block includes the effects of choked flow: the mass flow rate remains at its value at  $\beta = 0$ , while the pressure ratio continues to change. To constrain the compressor performance within the map boundaries, the block extrapolates isentropic efficiency to the nearest point.

You can choose to be notified when the operating point pressure ratio exceeds the surge pressure ratio. Set **Report when surge margin is negative** to **Warning** to receive a warning or to **Error** to stop the simulation when this occurs.

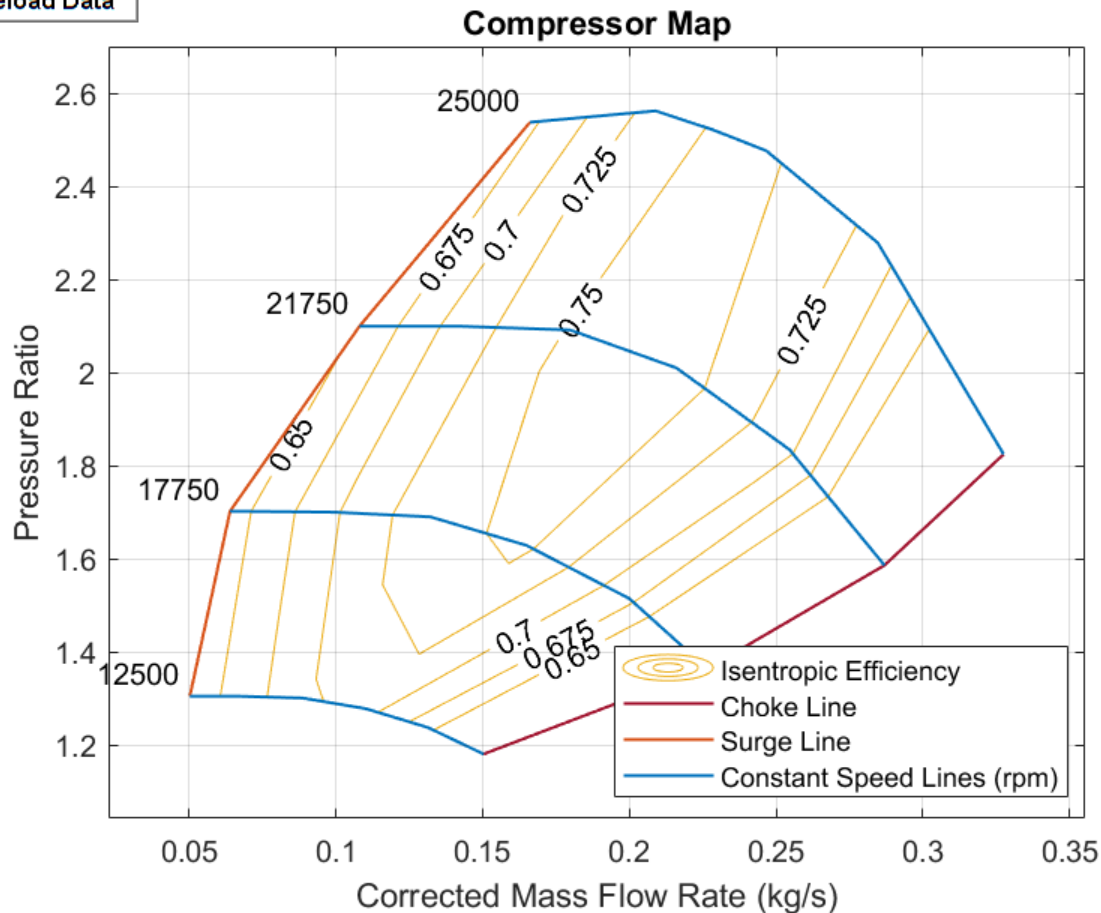
### **Visualizing the Block Compressor Map**

To visualize the block map, right-click the block and select **Fluids > Plot Compressor Map**.

Each time you modify the block settings, click **Reload Data** on the figure window.



Reload Data



### Tabulated Parameterization Default Compressor Map

#### Continuity Equations

The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_B$  is the mass flow rate at port **B**.

The block computes the energy balance equation as

$$\Phi_A + \Phi_B + P_{fluid} = 0,$$

where:

- $\Phi_A$  is the energy flow rate at port **A**.
- $\Phi_B$  is the energy flow rate at port **B**.
- $P_{fluid}$  is the hydraulic power delivered to the fluid, which is determined from the change in specific :  $P_{fluid} = \dot{m}_A \Delta h_{total}$ .

### Assumptions and Limitations

- The block assumes that superheated fluid enters at **A**.
- The block only defines compressor map flow from port **A** to port **B**. Reverse flow results may not be accurate.
- The block only represents dynamic compressors.

### Ports

#### Output

##### SM — Surge margin

physical signal

Physical signal output port associated with the surge margin at a given mass flow rate. The block calculates the surge margin as

$$SM(\dot{m}_{corr}) = \frac{p_{r, surge}(\dot{m}_{corr})}{p_r(\dot{m}_{corr})} - 1.$$

#### Dependencies

To enable this port, set **Parameterization** to Tabulated.

#### Conserving

##### A — Compressor inlet

two-phase fluid

Two-phase fluid conserving port associated with the compressor inlet.

##### B — Compressor outlet

two-phase fluid

Two-phase fluid conserving port associated with the compressor outlet.

##### C — Compressor casing

mechanical rotational

Mechanical rotational conserving port associated with the compressor case.

##### R — Compressor shaft

mechanical rotational

Mechanical rotational conserving port associated with the compressor shaft.

### Parameters

#### Compressor Map

##### Parameterization — Compressor performance parameterization

Analytical (default) | Tabulated

Compressor performance parameterization.

- **Analytical:** A pressure ratio corrected mass flow rate curve defines peak compressor performance. You can choose to include isentropic efficiency as a constant or analytically.
- **Tabulated:** A user-supplied compressor map defines the compressor performance. The compressor operating points are determined by linear interpolation between the corrected mass flow rate, pressure ratio, and isentropic efficiency tables at given points in the user-provided corrected shaft speed and  $\beta$  vectors.

### **Corrected speed at design point – Operational corrected shaft speed**

25000 rpm (default) | positive scalar

Shaft speed at the intended compressor pressure ratio and corrected mass flow rate, corrected for temperature.

#### **Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

### **Pressure ratio at design point – Operational outlet-to-inlet pressure ratio**

2.2 (default) | positive scalar

Outlet-to-inlet pressure ratio at the intended compressor corrected mass flow rate.

#### **Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

### **Corrected mass flow rate at design point – Operational corrected mass flow rate**

0.20 kg/s (default) | positive scalar

Mass flow rate at the intended compressor pressure ratio, corrected for temperature and pressure.

#### **Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

### **Efficiency specification – Isentropic efficiency option**

Constant (default) | Analytical

Option to parameterize efficiency using a constant value or analytically. Choose a constant or variable (analytical) model.

#### **Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

### **Maximum isentropic efficiency – Maximum compressor efficiency**

0.887 (default) | positive scalar in the range (0,1]

Maximum compressor isentropic efficiency. Isentropic efficiency is the ratio of isentropic change to actual change.

#### **Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

### **Minimum isentropic efficiency – Minimum compressor efficiency**

0.5 (default) | positive scalar in the range (0,1]

Minimum compressor isentropic efficiency. Isentropic efficiency is the ratio of isentropic change to actual change.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Pressure ratio at maximum efficiency point – Pressure ratio at compressor maximum efficiency**

2.1 (default) | positive scalar

Pressure ratio at maximum efficiency. The point of maximum efficiency does not necessarily coincide with the compressor design point.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Corrected mass flow rate at maximum efficiency point – Corrected mass flow rate at compressor maximum efficiency**

0.19 kg/s (default) | positive scalar

Mass flow rate at maximum efficiency, corrected for temperature and pressure. The point of maximum efficiency does not necessarily coincide with the compressor design point.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Constant isentropic efficiency – Constant isentropic efficiency value**

0.8 (default) | positive scalar

Value of constant isentropic efficiency.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Constant.

**Corrected speed index vector, N – Vector of corrected shaft speeds**

250 .\* [50, 71, 87, 100] rpm (default) | vector

Vector of corrected shaft speeds.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Beta index vector, beta – Vector of intervals**

0 : 1 / 5 : 1 (default) | vector of elements in the range [0,1]

Vector of relative positions along the corrected speed lines. Choked flow is defined as  $\beta = 0$  and surge flow is defined at  $\beta = 1$ .  $\beta$  lines are perpendicular to the compressor shaft constant speed lines,  $N$ .

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Pressure ratio table,  $pr(N, \beta)$  – Compressor map pressure ratio data**

[1.1814, 1.2385, 1.2792, 1.3017, 1.3057, 1.3057; 1.3648, 1.5157, 1.6298, 1.691, 1.7011, 1.7032; 1.587, 1.8357, 2.011, 2.0925, 2.1006, 2.1006; 1.8255, 2.28, 2.4777, 2.5225, 2.5633, 2.5389] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of compressor outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. The block uses linear interpolation between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector,  $N$**  parameter.
- $N$  is the number of vector elements in the **Beta index vector,  $\beta$**  parameter.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Corrected mass flow rate table,  $mdot(N, \beta)$  – Compressor map corrected mass flow rate data**

[.1503, .1313, .11, .0887, .0668, .0502; .2265, .1999, .1649, .1322, .0992, .0639; .2869, .2545, .216, .1798, .1424, .108; .3275, .2846, .2466, .2285, .209, .1661] kg/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of corrected mass flow rates at the specified corrected shaft speed and  $\beta$  value. The block uses linear interpolation between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector,  $N$**  parameter.
- $N$  is the number of vector elements in the **Beta index vector,  $\beta$**  parameter.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Isentropic efficiency table,  $\eta(N, \beta)$  – Compressor map isentropic efficiency data**

[.56, .66, .71, .695, .659, .635; .558, .682, .755, .743, .697, .638; .57, .705, .765, .752, .712, .652; .552, .718, .755, .752, .736, .67] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of compressor isentropic efficiencies at the specified corrected shaft speed and  $\beta$  value. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector,  $N$**  parameter.
- $N$  is the number of vector elements in the **Beta index vector,  $\beta$**  parameter.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Report when surge margin is negative – Negative surge margin notification**

None (default) | Warning | Error

Whether the block does nothing, generates a warning, or generates an error when it detects a negative surge margin.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Report when fluid is not fully vapor – Fluid not fully vapor notification**

None (default) | Warning | Error

Whether the block does nothing, generates a warning, or generates an error when it detects fluid that is not fully vapor.

**Map Coefficients**

To enable the **Map Coefficients** parameters, set **Parameterization** to Analytical.

**Spine shape, a – Spine shape exponent**

1.5 (default) | positive scalar

Exponent in the analytical parameterization of the compressor map that characterizes the spine shape.

**Speed line spread, b – Constant speed line spacing exponent**

5 (default) | positive scalar

Exponent in the analytical parameterization of the compressor map that characterizes the constant speed line spacing.

**Speed line roundness, k – Constant speed line shape coefficient**

0.03 (default) | positive scalar

Coefficient in the analytical parameterization of the compressor map that characterizes the constant speed line shape.

**Efficiency peak flatness orthogonal to spine, c – Flatness orthogonal to spine exponent**

3 (default) | positive scalar

Exponent associated with the compressor map peak flatness orthogonal to the spine.

**Efficiency peak flatness along spine, d – Along spine flatness exponent**

4 (default) | positive scalar

Exponent associated with the efficiency map peak flatness along the spine.

**Efficiency contour gradient orthogonal to spine, C – Orthogonal gradient coefficient**

15 (default) | positive scalar

Coefficient associated with the efficiency contour gradient orthogonal to the spine.

**Efficiency contour gradient along spine, D – Along spine gradient coefficient**

1.0 (default) | positive scalar

Coefficient associated with the efficiency contour gradient along the spine.

**Reference data****Reference pressure for corrected flow – Correcting pressure**

0.101325 MPa (default) | positive scalar

Reference inlet pressure for compressor map. When **Parameterization** is set to **Tabulated**, the data supplier specifies this value. When you set **Parameterization** to **Analytical**, this is the inlet pressure at the design operating condition.

**Reference temperature for corrected flow – Correcting temperature**

373.15 K (default) | positive scalar

Reference inlet temperature for compressor map. When you set **Parameterization** to **Tabulated**, the data supplier specifies this value. When you set **Parameterization** to **Analytical**, this is the inlet temperature at the design operating condition.

**Mechanical efficiency – Efficiency of conversion to torque**

0.9 (default) | positive scalar in the range [0,1]

Ratio of the power delivered to the fluid flow to the power driving the mechanical shaft.

**Inlet area at port A – Compressor inlet area**0.01 m<sup>2</sup> (default) | positive scalar

Compressor inlet cross-sectional area.

**Outlet area at port B – Compressor outlet area**0.01 m<sup>2</sup> (default) | positive scalar

Compressor outlet cross-sectional area.

**References**

- [1] Greitzer, E. M. et al. "N+3 Aircraft Concept Designs and Trade Studies. Volume 2: Appendices - Design Methodologies for Aerodynamics, Structures, Weight, and Thermodynamic Cycles." *NASA Technical Report*, 2010.
- [2] Kurzke, Joachim. "How to Get Component Maps for Aircraft Gas Turbine Performance Calculations." *Volume 5: Manufacturing Materials and Metallurgy; Ceramics; Structures and Dynamics; Controls, Diagnostics and Instrumentation; Education; General*, American Society of Mechanical Engineers, 1996, p. V005T16A001.
- [3] Plencner, Robert M. "Plotting component maps in the Navy/NASA Engine Program (NNEP): A method and its usage." *NASA Technical Memorandum*, 1989.

**Version History**

Introduced in R2022a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Compressor (G)



# Compressor (G)

Gas compressor in a thermodynamic cycle

**Library:** Simscape / Fluids / Gas / Turbomachinery



## Description

The Compressor (G) block represents a dynamic compressor, such as a centrifugal or axial compressor, in a gas network. You can parameterize the block analytically based on the design point or by using a tabulated compressor map by setting **Parameterization** to **Analytical** or **Tabulated**, respectively. A positive rotation of port **R** relative to port **C** causes fluid to flow from port **A** to port **B**. Port **R** and port **C** are mechanical rotational conserving ports associated with the compressor shaft and casing, in that order.

The *surge margin* is the ratio between the surge pressure ratio at a given mass flow rate and the operating point pressure ratio minus 1. When you set **Parameterization** to **Tabulated**, the block outputs the surge margin at port **SM**.

The *design point* of the compressor is the design operational pressure ratio across and mass flow rate through the compressor during simulation. The compressor operating point and the point of maximum efficiency do not need to coincide.

## Compressor Map

The map plots the isentropic efficiency of the compressor between the two extremes of choked flow and surge flow. The map plots the lines of constant corrected shaft speed between the two extremes of choked flow and surge flow. Each corrected speed line tells you how pressure ratio varies with corrected mass flow rate when the shaft spins at the corresponding corrected speed. The variable  $\beta$  indicates the relative position along the corrected speed lines between the two extremes. Choked flow corresponds to  $\beta = 0$ , and surge flow corresponds to  $\beta = 1$ . The map also plots contours of isentropic efficiency as a function of pressure ratio and corrected mass flow rate. This provides a relative indication of how much power the compressor needs to operate at various combinations of pressure ratio and corrected mass flow rate.

## Corrected Mass Flow Rate

Due to the large changes in pressure and temperature inside a compressor, the compressor map plots performance in terms of a corrected mass flow rate. The corrected mass flow rate is adjusted from the inlet mass flow rate with a reference pressure and reference temperature:

$$\dot{m}_{corr} = \dot{m}_A \left( \frac{p_A}{p_{ref}} \sqrt{\frac{T_A}{T_{ref}}} \right),$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $T_A$  is the temperature at port **A**.

- $T_{ref}$  is the **Reference temperature for corrected flow**. When you set **Parameterization** to **Analytical**, this is the inlet temperature at the design operating condition.
- $\dot{m}_{corr}$  is the corrected mass flow rate.

When you set **Parameterization** to **Analytical**, the block uses the **Corrected mass flow rate at design point** parameter.

When you set **Parameterization** to **Tabulated**, the block uses the **Corrected mass flow rate table,  $\dot{m}(N,\beta)$**  parameter.

- $p_A$  is the pressure at port **A**.
- $p_{ref}$  is the **Reference pressure for corrected flow** parameter. When using the analytical parameterization, this is the inlet pressure at the design operating condition.

The block derives  $T_A$  from the specific internal energy,  $u_A$ , and specific pressure,  $p_A$ .

### Corrected Speed

The block also adjusts the shaft speed,  $\omega$ , according to the reference temperature, such that the corrected shaft speed is

$$\omega_{corr} = \frac{\omega}{\sqrt{\frac{T_A}{T_{ref}}}}$$

### Shaft Torque

The block calculates the shaft torque,  $\tau$ , as:

$$\tau = \frac{\dot{m}_A \Delta h_{total}}{\eta_m \omega}$$

where:

- $\Delta h_{total}$  is the change in specific total enthalpy.
- $\eta_m$  is the compressor **Mechanical efficiency**.
- $\omega$  is the relative shaft angular velocity,  $\omega_R - \omega_C$ .

The block relates the efficiency in the compressor map as

$$\Delta h_{total} = \frac{\Delta h_{isen}}{\eta_{isen}}$$

where

- $\Delta h_{isen}$  is the isentropic change in specific total enthalpy.
- $\eta_{isen}$  is the isentropic efficiency.

A threshold region when flow approaches zero ensures that no torque is generated when the flow rate is near zero or reversed.

### Analytical Parameterization

You can generate the compressor map analytically by setting **Parameterization** to **Analytical**. The block fits a model of the compressor map based on Greitzer et al, 2010 to the specified values for the

**Corrected speed at design point, Pressure ratio at design point, and Corrected mass flow rate at design point** parameters. This method does not use  $\beta$  lines and the block does not report a surge margin.

### Pressure Ratio

The block finds the pressure ratio at a given shaft speed and mass flow rate as:

$$\pi = 1 + (\pi_D - 1) \left[ \tilde{N}^{ab} + 2\tilde{N}k \ln \left( 1 - \frac{\tilde{m} - \tilde{N}^b}{k} \right) \right],$$

where:

- $\pi_D$  is the **Pressure ratio at design point** parameter.
- $\tilde{N}$  is the normalized corrected shaft speed,

$$\frac{N}{N_D},$$

where  $N_D$  is the **Corrected speed at design point** parameter.

- $\tilde{m}$  is the normalized corrected mass flow rate,

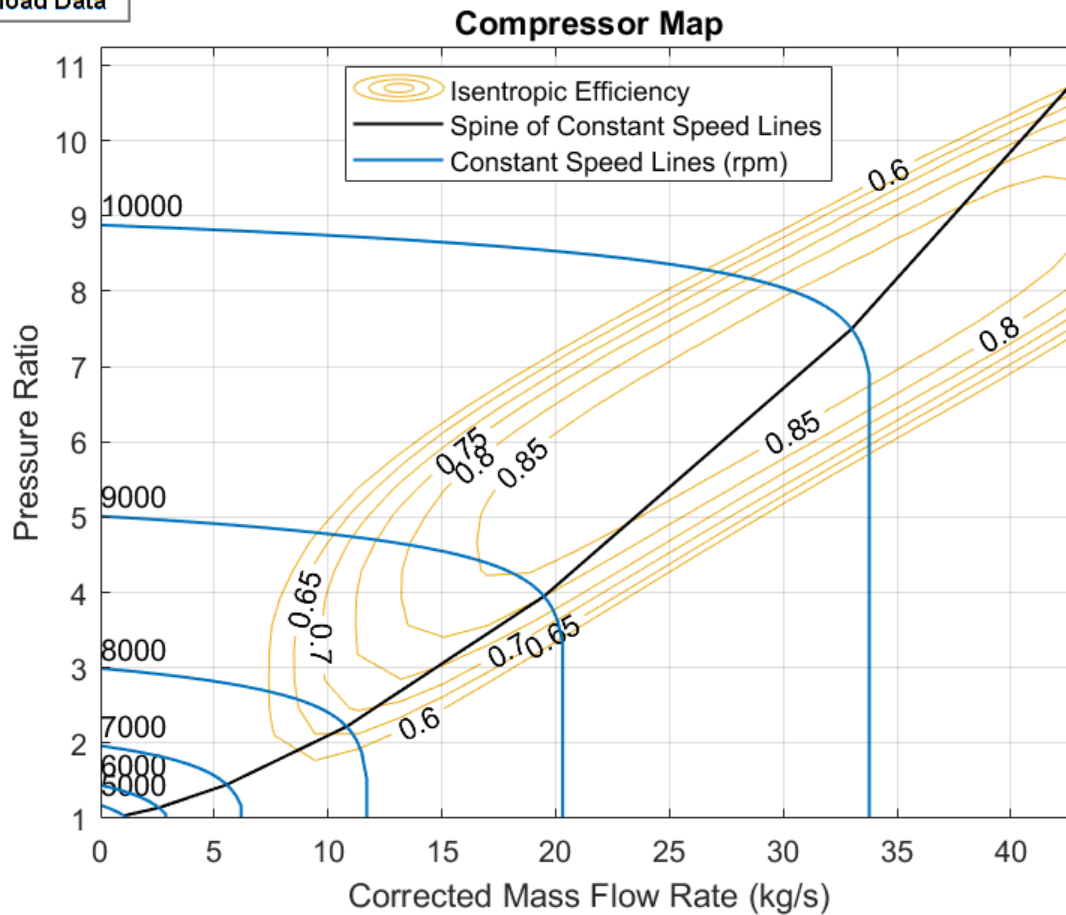
$$\frac{\dot{m}_{corr}}{\dot{m}_D},$$

where  $\dot{m}_D$  is the **Corrected mass flow rate at design point**.

- $a$  is the **Spine shape, a** parameter.
- $b$  is the **Speed line spread, b** parameter.
- $k$  is the **Speed line roundness, k** parameter.

The *spine* refers to the black line where the isentropic efficiency contours start to bend. The map *speed lines* are the shaft constant-speed lines that intersect the spine perpendicularly.

Reload Data



### Analytical Parameterization Default Compressor Map

#### Isentropic Efficiency Parameterization

When you set **Efficiency specification** to Analytical, the block models variable compressor efficiency as:

$$\eta = \eta_0 \left( 1 - C \left| \frac{\tilde{p}}{\tilde{m}^{a+\Delta a} - 1} - \tilde{m} \right|^c - D \left| \frac{\tilde{m}}{\tilde{m}_0} - 1 \right|^d \right),$$

where:

- $\eta_0$  is the **Maximum isentropic efficiency** parameter.
- $C$  is the **Efficiency contour gradient orthogonal to spine, C** parameter.
- $D$  is the **Efficiency contour gradient along spine, D** parameter.
- $c$  is the **Efficiency peak flatness orthogonal to spine, c** parameter.
- $d$  is the **Efficiency peak flatness along spine, d** parameter.
- $\tilde{p}$  is the normalized corrected pressure ratio,

$$\frac{\pi - 1}{\pi_D - 1},$$

where  $\pi_D$  is the **Corrected pressure ratio at design point** parameter.

- $\tilde{m}_0$  is the normalized corrected mass flow rate at which the compressor reaches its **Maximum isentropic efficiency** parameter.

You can adjust the efficiency variables for different performance characteristics.

Alternatively, you can choose a constant efficiency value by using the **Constant isentropic efficiency** parameter.

### Tabulated Data Parameterization

When you set **Parameterization** to **Tabulated**, the isentropic efficiency, pressure ratio, and corrected mass flow rate of the compressor are functions of the corrected speed,  $N$ , and the map index,  $\beta$ . The block uses linear interpolation between data points for the efficiency, pressure ratio, and corrected mass flow rate.

If  $\beta$  exceeds 1, compressor surge occurs, and the block assumes the pressure ratio remains at  $\beta = 1$ , while the mass flow rate continues to change. If the simulation conditions fall below  $\beta = 0$ , the block includes the effects of choked flow: the mass flow rate remains at its value at  $\beta = 0$ , while the pressure ratio continues to change. To constrain the compressor performance within the map boundaries, the block extrapolates isentropic efficiency to the nearest point.

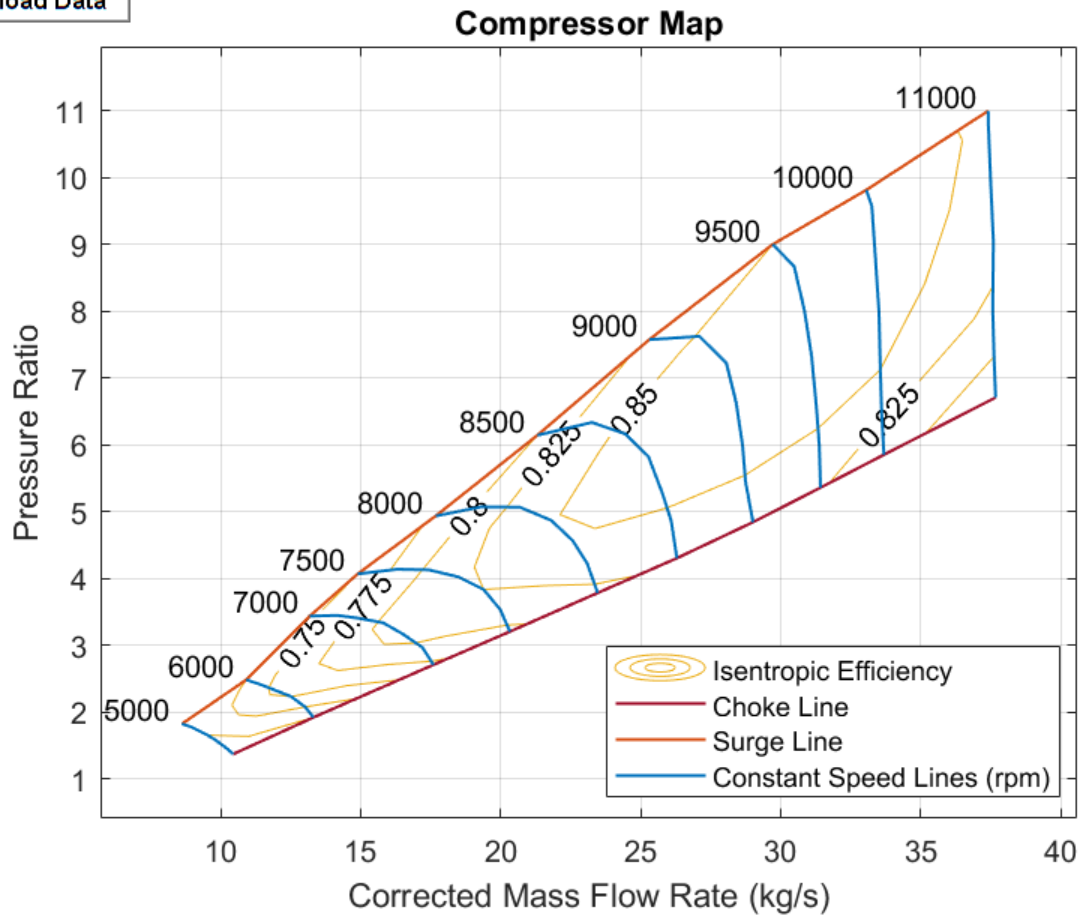
You can choose to be notified when the operating point pressure ratio exceeds the surge pressure ratio. Set **Report when surge margin is negative** to **Warning** to receive a warning or to **Error** to stop the simulation when this occurs.

### Visualizing the Block Compressor Map

To visualize the block map, right-click the block and select **Fluids > Plot Compressor Map**.

Each time you modify the block settings, click **Reload Data** on the figure window.

Reload Data



### Tabulated Parameterization Default Compressor Map

#### Continuity Equations

The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_B$  is the mass flow rate at port **B**.

The block computes the energy balance equation as

$$\Phi_A + \Phi_B + P_{fluid} = 0,$$

where:

- $\Phi_A$  is the energy flow rate at port **A**.
- $\Phi_B$  is the energy flow rate at port **B**.
- $P_{fluid}$  is the hydraulic power delivered to the fluid, which is determined from the change in specific :  $P_{fluid} = \dot{m}_A \Delta h_{total}$ .

## Assumptions and Limitations

- The block assumes that superheated fluid enters at **A**.
- The block only defines compressor map flow from port **A** to port **B**. Reverse flow results may not be accurate.
- The block only represents dynamic compressors.

## Ports

### Conserving

#### A — Gas inlet

gas

Fluid entry port.

#### B — Gas outlet

gas

Fluid exit port.

#### C — Compressor casing

mechanical translational

Port associated with the compressor casing.

#### R — Compressor shaft

mechanical translational

Port associated with the compressor shaft torque and angular velocity.

## Output

#### SM — Surge margin

physical signal

Physical signal output port associated with the surge margin at a given mass flow rate. The block calculates the surge margin as

$$SM(\dot{m}_{corr}) = \frac{p_{r, surge}(\dot{m}_{corr})}{p_r(\dot{m}_{corr})} - 1.$$

## Dependencies

To enable this port, set **Parameterization** to Tabulated.

## Parameters

### Compressor Map

#### Parameterization — Compressor performance parameterization

Analytical (default) | Tabulated

Compressor performance parameterization.

- **Analytical:** A pressure ratio-corrected mass flow rate curve defines peak compressor performance. You can choose to model isentropic efficiency as a constant or analytically.
- **Tabulated:** A user-supplied compressor map defines the compressor performance. The compressor operating points are determined by linear interpolation between the corrected mass flow rate, pressure ratio, and isentropic efficiency tables at given points in the user-provided corrected shaft speed and  $\beta$  vectors. The default map comes from data reported in [3].

**Corrected speed at design point – Operational corrected shaft speed**

10000 rpm (default) | positive scalar

Shaft speed at the intended compressor pressure ratio and corrected mass flow rate, corrected for temperature.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Pressure ratio at design point – Operational outlet-to-inlet pressure ratio**

26 (default) | positive scalar

Outlet-to-inlet pressure ratio at the intended compressor corrected mass flow rate.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Corrected mass flow rate at design point – Operational corrected mass flow rate**

30 kg/s (default) | positive scalar

Mass flow rate at the intended compressor pressure ratio, corrected for temperature and pressure.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Efficiency specification – Isentropic efficiency model**

Analytical (default) | Constant

Isentropic efficiency model type. Choose a constant or variable (analytical) model.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Maximum isentropic efficiency – Maximum compressor efficiency**

0.887 (default) | positive scalar in the range (0,1]

Maximum compressor isentropic efficiency. Isentropic efficiency is the ratio of isentropic change to actual change.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Corrected mass flow rate at maximum efficiency point – Corrected mass flow rate at compressor maximum efficiency**

24 kg/s (default) | positive scalar



Mass flow rate at maximum efficiency, corrected for temperature and pressure. The point of maximum efficiency does not necessarily coincide with the compressor design point.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Pressure ratio at maximum efficiency point — Pressure ratio at compressor maximum efficiency**

17 (default) | positive scalar

Pressure ratio at maximum efficiency. The point of maximum efficiency does not necessarily coincide with the compressor design point.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Constant efficiency value — Constant isentropic efficiency value**

0.8 (default) | positive scalar in the range (0,1]

Value of constant isentropic efficiency in the analytical parameterization.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Constant.

**Corrected speed index vector, N — Vector of corrected shaft speeds**

100 .\* [50, 60, 70, 75, 80, 85, 90, 95, 100, 110] rpm (default) | vector

Vector of corrected shaft speeds.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Beta index vector, beta — Vector of intervals**

0 : 1 / 6 : 1 (default) | vector of elements in the range [0,1]

Vector of relative positions along the corrected speed lines. Choked flow is defined as  $\beta = 0$  and surge flow is defined at  $\beta = 1$ .  $\beta$  lines are perpendicular to the compressor shaft constant speed lines,  $N$ .

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Pressure ratio table, pr(N,beta) — Compressor map pressure ratio data**

[1.369, 1.459, 1.587, 1.654, 1.734, 1.775, 1.82; 1.918, 2.075, 2.229, 2.318, 2.405, 2.456, 2.481; 2.706, 2.966, 3.168, 3.334, 3.404, 3.445, 3.435; 3.203, 3.533, 3.833, 4.021, 4.127, 4.135, 4.066; 3.782, 4.222, 4.565, 4.867, 5.065, 5.07, 4.934; 4.302, 4.861, 5.285, 5.821, 6.161, 6.334, 6.142; 4.841, 5.445, 5.988, 6.628, 7.222, 7.623, 7.573; 5.358, 5.997, 6.589, 7.334, 8.012, 8.668, 9; 5.851, 6.491, 7.124, 7.982, 8.754, 9.57, 9.814; 6.707, 7.321, 8.034, 9.047, 9.94, 10.834, 10.998] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of compressor outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector**,  $N$  parameter.
- $N$  is the number of vector elements in the **Beta index vector**,  $\beta$  parameter.

#### Dependencies

To enable this parameter, set **Parameterization** to Tabulated.

#### Corrected mass flow rate table, $\dot{m}(N,\beta)$ – Compressor map corrected mass flow rate data

[10.45, 10.203, 9.784, 9.526, 9.144, 8.947, 8.615; 13.315, 13.018, 12.525, 11.984, 11.455, 11.086, 10.914; 17.601, 17.204, 16.502, 15.8, 14.903, 14.179, 13.184; 20.331, 19.983, 19.39, 18.492, 17.435, 16.293, 14.895; 23.466, 23.092, 22.572, 21.807, 20.687, 19.3, 17.682; 26.295, 26.091, 25.766, 25.28, 24.453, 23.26, 21.311; 29.013, 28.747, 28.641, 28.412, 28.06, 27.098, 25.306; 31.424, 31.379, 31.273, 31.103, 30.849, 30.484, 29.718; 33.688, 33.606, 33.561, 33.513, 33.392, 33.258, 33.059; 37.678, 37.621, 37.575, 37.598, 37.501, 37.415, 37.413] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of corrected mass flow rates at the specified corrected shaft speed and  $\beta$  value. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector**,  $N$  parameter.
- $N$  is the number of vector elements in the **Beta index vector**,  $\beta$  parameter.

#### Dependencies

To enable this parameter, set **Parameterization** to Tabulated.

#### Isentropic efficiency table, $\eta(N,\beta)$ – Compressor map isentropic efficiency data

[.68, .69, .695, .7, .701, .705, .704; .7, .725, .75, .755, .745, .73, .725; .77, .795, .81, .805, .78, .765, .745; .795, .812, .825, .82, .805, .78, .75; .82, .837, .848, .849, .835, .805, .78; .83, .845, .856, .86, .855, .84, .8; .83, .848, .859, .869, .86, .852, .83; .828, .845, .857, .869, .862, .855, .85; .806, .83, .85, .86, .859, .857, .853; .79, .8, .82, .835, .845, .848, .849] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of compressor isentropic efficiencies at the specified corrected shaft speed and  $\beta$  value. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Corrected speed index vector**,  $N$  parameter.
- $N$  is the number of vector elements in the **Beta index vector**,  $\beta$  parameter.

#### Dependencies

To enable this parameter, set **Parameterization** to Tabulated.

**Report when surge margin is negative – Whether to notify if pressure ratio exceeds surge pressure ratio**

None (default) | Warning | Error

Whether to notify if the compressor operating point pressure ratio exceeds the surge pressure ratio at the given corrected mass flow rate.

**Dependencies**

To enable this parameter, set **Parameterization** to Tabulated.

**Map Coefficients**

To enable the **Map Coefficients** parameters, set **Parameterization** to Analytical.

**Spine shape, a – Spine shape exponent**

1.5 (default) | positive scalar

Exponent in the analytical parameterization of the compressor map that characterizes the spine shape.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Speed line spread, b – Constant speed line spacing exponent**

5 (default) | positive scalar

Exponent in the analytical parameterization of the compressor map that characterizes the constant speed line spacing.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Speed line roundness, k – Constant speed line shape coefficient**

0.03 (default) | positive scalar

Coefficient in the analytical parameterization of the compressor map that characterizes the constant speed line shape.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical.

**Efficiency peak flatness orthogonal to spine, c – Exponent characterizing shape of analytical isentropic efficiency**

3 (default) | positive scalar

Exponent associated with the compressor map peak flatness orthogonal to the spine.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Efficiency peak flatness along spine, d – Exponent characterizing shape of analytical isentropic efficiency**

4 (default) | positive scalar

Exponent associated with the efficiency map peak flatness along the spine.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Efficiency contour gradient orthogonal to spine, C – Coefficient characterizing shape of analytical isentropic efficiency**

15 (default) | positive scalar

Coefficient associated with the efficiency contour gradient orthogonal to the spine.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Efficiency contour gradient along spine, D – Coefficient characterizing shape of analytical isentropic efficiency**

1.0 (default) | positive scalar in the range (0,1]

Coefficient associated with the efficiency contour gradient along the spine.

**Dependencies**

To enable this parameter, set **Parameterization** to Analytical and **Efficiency specification** to Analytical.

**Reference Data****Reference pressure for corrected flow – Correcting pressure**

0.101325 MPa (default) | positive scalar

Reference inlet pressure for compressor map. When **Parameterization** is set to Tabulated, the data supplier specifies this value. When you set **Parameterization** to Analytical, this is the inlet pressure at the design operating condition.

**Reference temperature for corrected flow – Correcting temperature**

288.15 K (default) | positive scalar

Reference inlet temperature for compressor map. When you set **Parameterization** to Tabulated, the data supplier specifies this value. When you set **Parameterization** to Analytical, this is the inlet temperature at the design operating condition.

**Mechanical efficiency – Efficiency of conversion to torque**

0.9 (default) | positive scalar in the range [0,1]

Ratio of the power delivered to the fluid flow to the power driving the mechanical shaft.

**Inlet area at port A – Compressor inlet area**1 m<sup>2</sup> (default) | positive scalar

Compressor inlet cross-sectional area.

**Outlet area at port B – Compressor outlet area**

1 m<sup>2</sup> (default) | positive scalar

Compressor outlet cross-sectional area.

## Version History

Introduced in R2021a

## References

- [1] Greitzer, E. M. et al. "N+3 Aircraft Concept Designs and Trade Studies. Volume 2: Appendices - Design Methodologies for Aerodynamics, Structures, Weight, and Thermodynamic Cycles." *NASA Technical Report*, 2010.
- [2] Kurzke, Joachim. "How to Get Component Maps for Aircraft Gas Turbine Performance Calculations." *Volume 5: Manufacturing Materials and Metallurgy; Ceramics; Structures and Dynamics; Controls, Diagnostics and Instrumentation; Education; General*, American Society of Mechanical Engineers, 1996, p. V005T16A001.
- [3] Plencner, Robert M. "Plotting component maps in the Navy/NASA Engine Program (NNEP): A method and its usage." *NASA Technical Memorandum*, 1989.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Thermostatic Expansion Valve (2P) | Turbine (G)

## Condenser Evaporator (2P-MA)

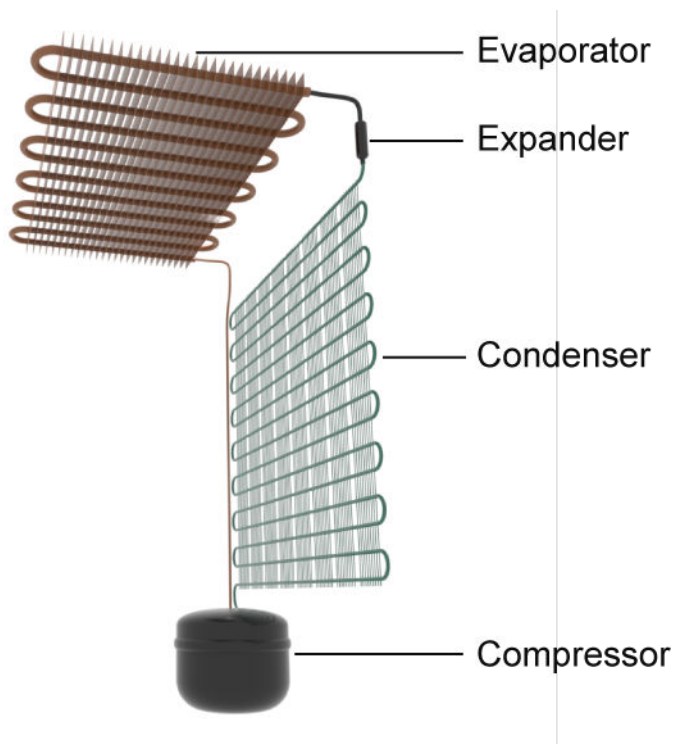
Models heat exchange between a moist air network and a network that can undergo phase change

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Condenser Evaporator (2P-MA) block models a heat exchanger with one moist air network, which flows between ports **A2** and **B2**, and one two-phase fluid network, which flows between ports **A1** and **B1**. The heat exchanger can act as a condenser or as an evaporator. The fluid streams can be aligned in parallel, counter, or cross-flow configurations.



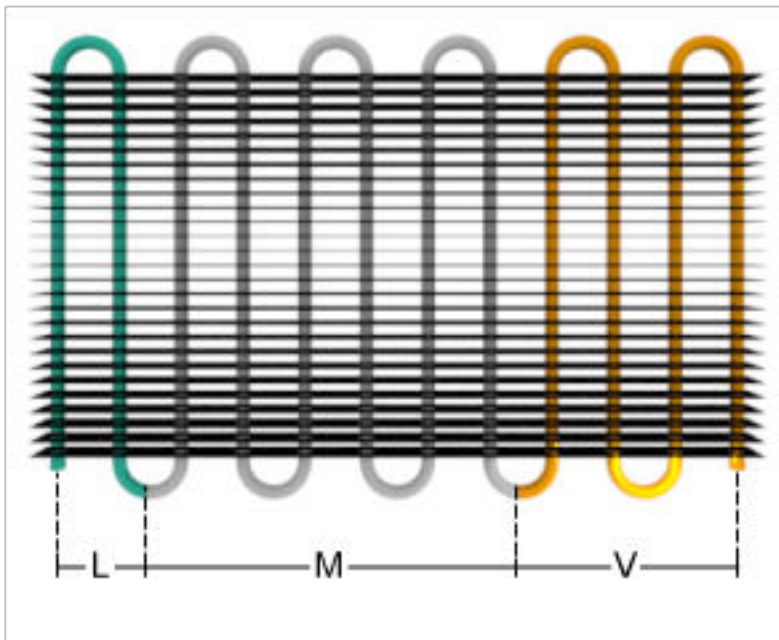
### Example Heat Exchanger for Refrigeration Applications

You can model the moist air side as flow within tubes, flow around the two-phase fluid tubing, or by an empirical, generic parameterization. The moist air side comprises air, trace gas, and water vapor that may condense throughout the heat exchange cycle. The block model accounts for energy transfer from the air to the liquid water condensation layer. This liquid layer does not collect on the heat

transfer surface and is assumed to be completely removed from the downstream moist air flow. The moisture condensation rate is returned as a physical signal at port **W**.

The block uses the Effectiveness-NTU (E-NTU) method to model heat transfer through the shared wall. Fouling on the exchanger walls, which increases thermal resistance and reduces the heat exchange between the two fluids, is also modeled. You can also optionally model fins on both the moist air and two-phase fluid sides. Pressure loss due to viscous friction on both sides of the exchanger can be modeled analytically or by generic parameterization, which you can use to tune to your own data.

You can model the two-phase fluid side as flow within a tube or a set of tubes. The two-phase fluid tubes use a boundary-following model to track the sub-cooled liquid (L), vapor-liquid mixture (M), and super-heated vapor (V) in three zones. The relative amount of space a zone occupies in the system is called a *zone length fraction* within the system.



### Zone Length Fractions in the Two-Phase Fluid Piping

The sum of the zone length fractions in the two-phase fluid tubing equals 1. Port **Z** returns the zone length fractions as a vector of physical signals for each of the three phases: [L, M, V].

### Heat Exchanger Configuration

The heat exchanger effectiveness is based on the selected heat exchanger configuration, the fluid properties in each phase, the tube geometry and flow configuration on each side of the exchanger, and the usage and size of fins.

**Flow Arrangement**

The **Flow arrangement** parameter assigns the relative flow paths between the two sides:

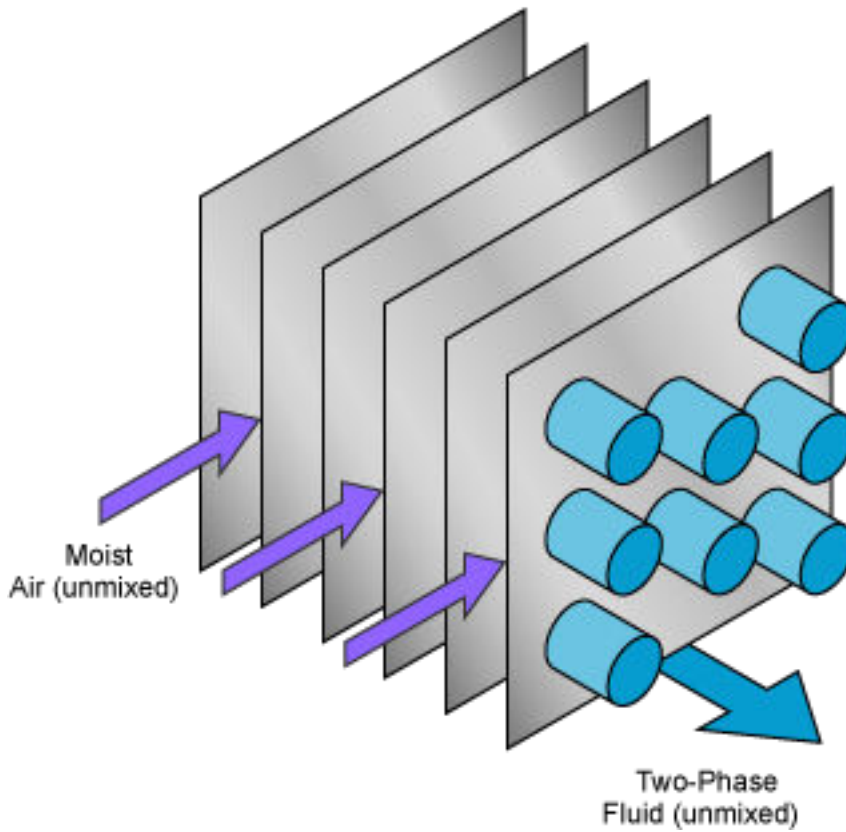
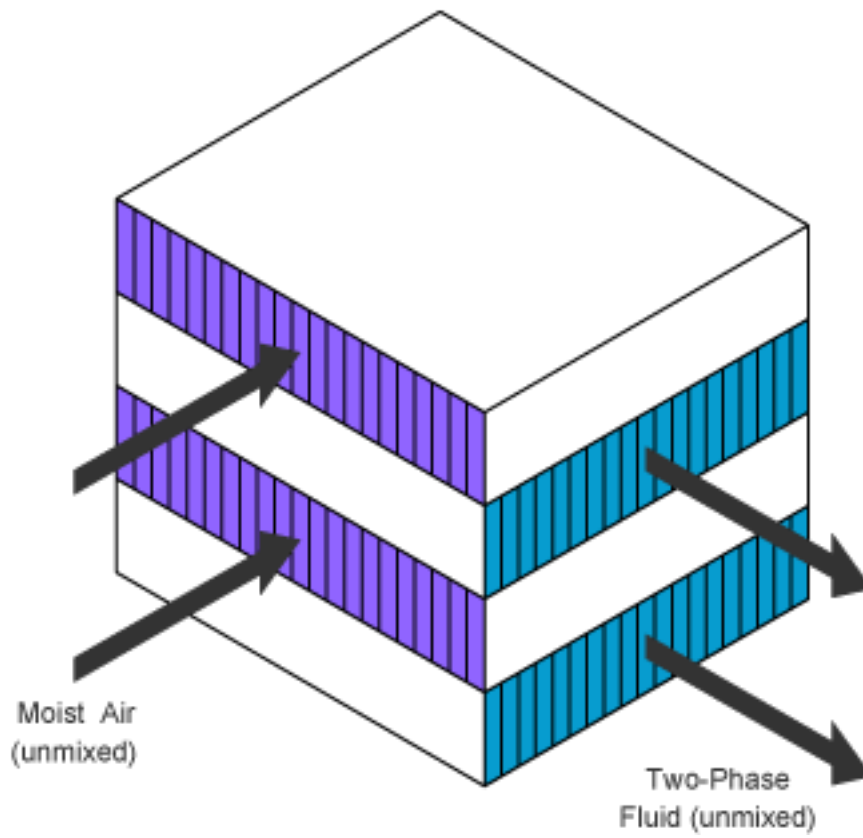
- Parallel flow indicates the fluids are moving in the same direction.
- Counter flow indicates the fluids are moving in parallel, but opposite directions.
- Cross flow indicates the fluids are moving perpendicular to each other.

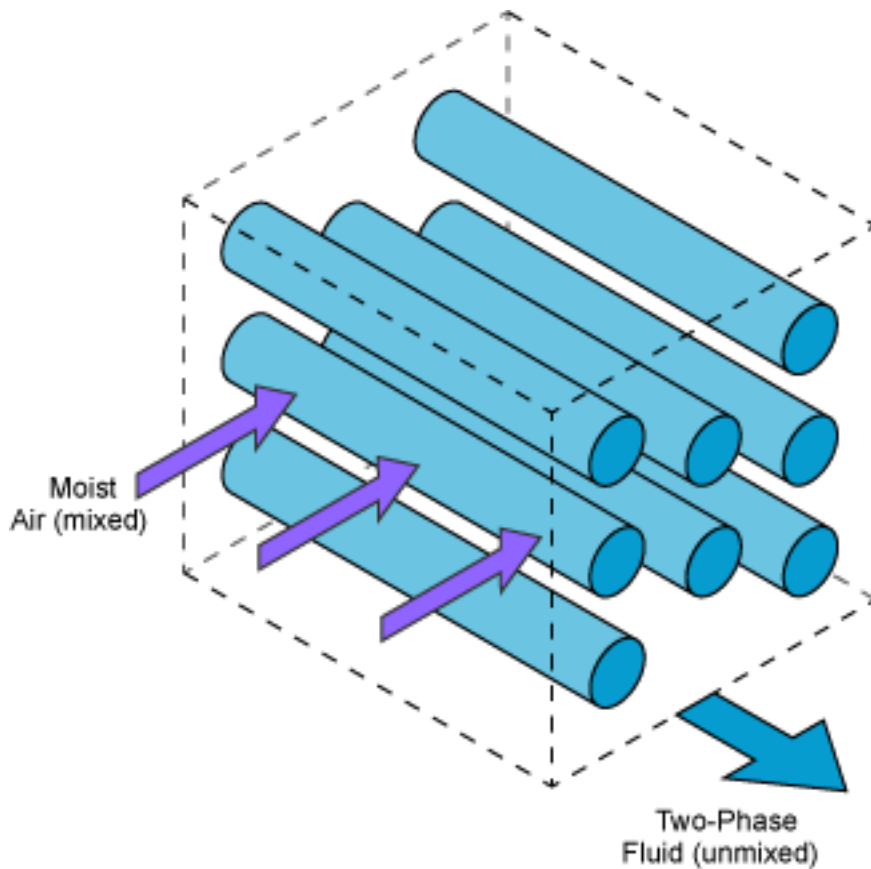
**Thermal Mixing**

When **Flow arrangement** is set to Cross flow, use the **Cross flow arrangement** parameter to indicate whether the two-phase fluid or moist air flows are separated into multiple paths by baffles or walls. Without these separations, the flow can mix freely and is considered *mixed*. Both fluids, one fluid, or neither fluid can be mixed in the cross-flow arrangement. Mixing homogenizes the fluid temperature along the direction of flow of the second fluid, and varies perpendicular to the second fluid flow.

Unmixed flows vary in temperature both along and perpendicular to the flow path of the second fluid.





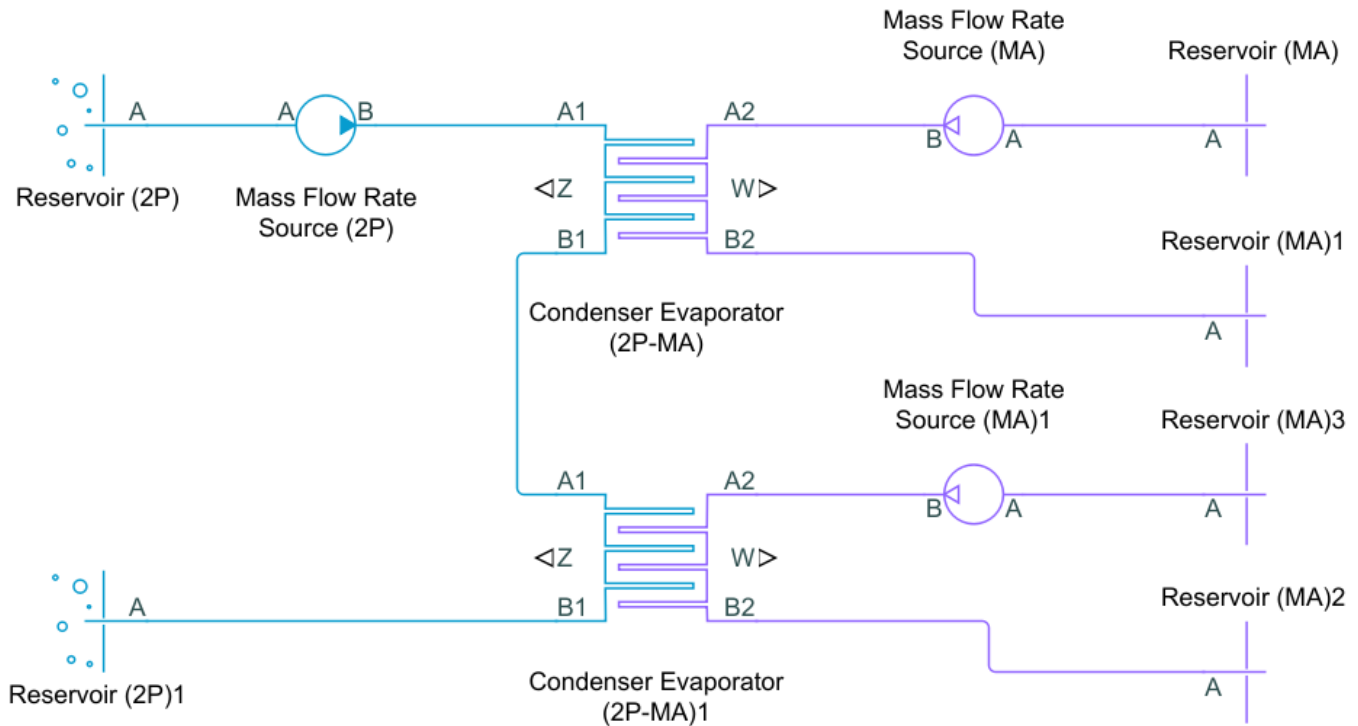


### Sample Cross-Flow Configurations

Note that the flow direction during simulation does not impact the selected flow arrangement setting. The ports on the block do not reflect the physical positions of the ports in the physical heat exchange system.

All flow arrangements are single-pass, which means that the fluids do not make multiple turns in the exchanger for additional points of heat transfer. To model a multi-pass heat exchanger, you can arrange multiple Condenser Evaporator (2P-MA) blocks in series or in parallel.

For example, to achieve a two-pass configuration on the two-phase fluid side and a single-pass configuration on the moist air side, you can connect the two-phase fluid sides in series and the moist air sides to the same input in parallel (such as two Mass Flow Rate Source blocks with half of the total mass flow rate), as shown below.



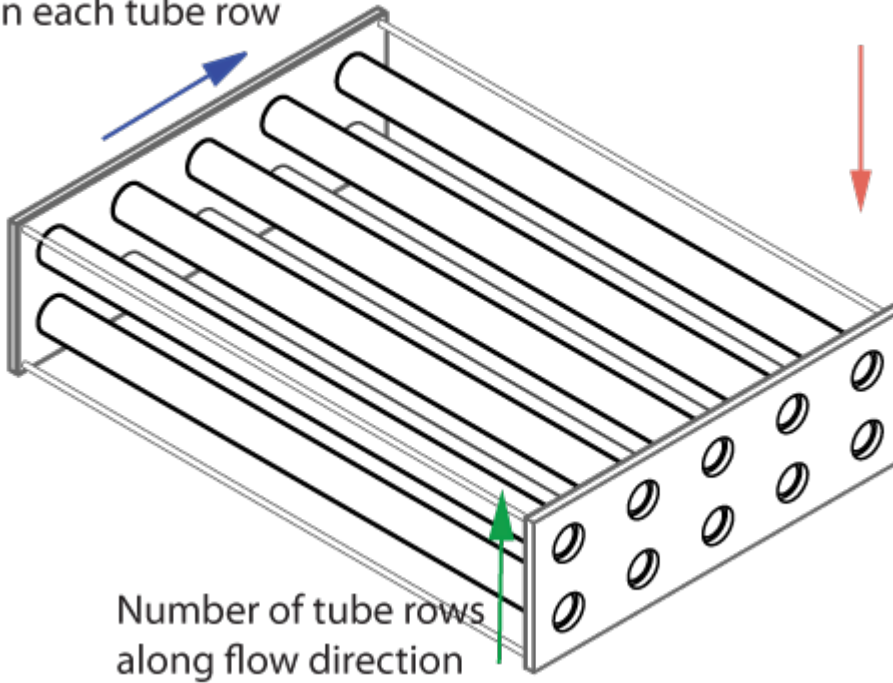
### Flow Geometry

The **Flow geometry** parameter sets the moist air flow arrangement as either inside a tube or set of tubes, or perpendicular to a tube bank. You can also specify an empirical, generic configuration. The two-phase fluid always flows inside a tube or set of tubes.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, use the **Tube bank grid arrangement** parameter to define the two-phase fluid tube bank alignment as either **Inline** or **Staggered**. The red, downward-pointing arrow indicates the direction of moist air flow. Also indicated in the **Inline** figure are the **Number of tube rows along flow direction** and the **Number of tube segments in each tube row** parameters. Here, *flow direction* refers to the moist air flow, and *tube* refers to the two-phase fluid tubing. The **Length of each tube segment in a tube row** parameter is indicated in the **Staggered** figure.

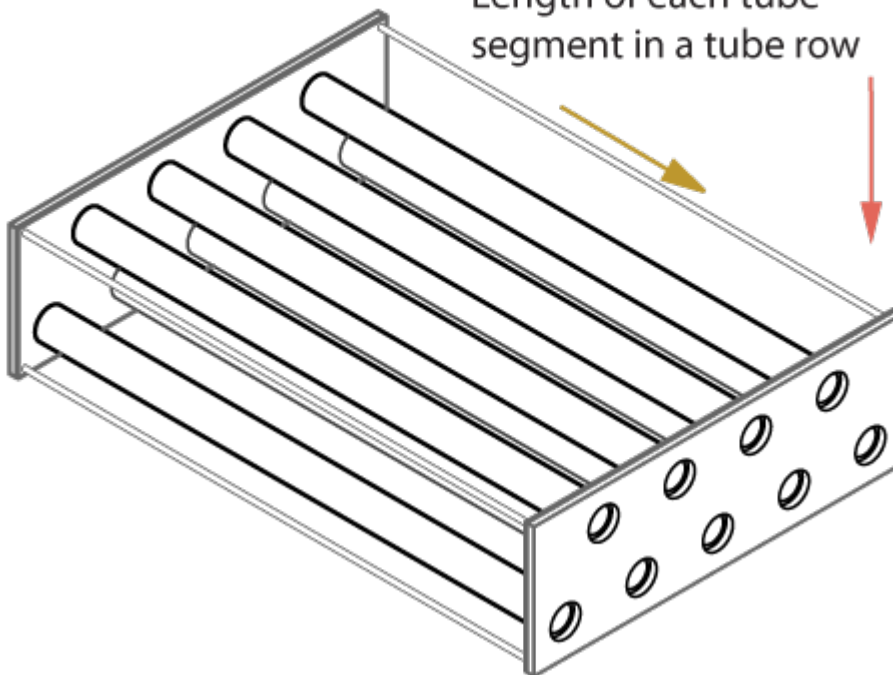
Number of tube segments  
in each tube row

### Inline



### Staggered

Length of each tube  
segment in a tube row



## Fins

The heat exchanger configuration is without fins when the **Total fin surface area** parameter is set to 0 m<sup>2</sup>. Fins introduce additional surface area for additional heat transfer. Each fluid side has a separate fin area.

## Effectiveness-NTU Heat Transfer

The heat transfer rate is calculated for each fluid phase. In accordance with the three fluid zones that occur on the two-phase fluid side of the heat exchanger, the heat transfer rate is calculated in three sections.

The heat transfer in a zone is calculated as:

$$Q_{zone} = \epsilon C_{\text{Min}}(T_{\text{In},2\text{P}} - T_{\text{In},\text{MA}}),$$

where:

- $C_{\text{Min}}$  is the lesser of the heat capacity rates of the two fluids in that zone. The heat capacity rate is the product of the fluid specific heat,  $c_p$ , and the fluid mass flow rate.  $C_{\text{Min}}$  is always positive.
- $T_{\text{In},2\text{P}}$  is the zone inlet temperature of the two-phase fluid.
- $T_{\text{In},\text{MA}}$  is the zone inlet temperature of the moist air.
- $\epsilon$  is the heat exchanger effectiveness.

Effectiveness is a function of the heat capacity rate and the number of transfer units,  $NTU$ , and also varies based on the heat exchanger flow arrangement, which is discussed in more detail in “Effectiveness by Flow Arrangement” on page 1-552. The  $NTU$  is calculated as:

$$NTU = \frac{z}{C_{\text{Min}}R},$$

where:

- $z$  is the individual zone length fraction.
- $R$  is the total thermal resistance between the two flows, due to convection, conduction, and any fouling on the tube walls:

$$R = \frac{1}{U_{2\text{P}}A_{\text{Th},2\text{P}}} + \frac{F_{2\text{P}}}{A_{\text{Th},2\text{P}}} + R_{\text{W}} + \frac{F_{\text{MA}}}{A_{\text{Th},\text{MA}}} + \frac{1}{U_{\text{MA}}A_{\text{Th},\text{MA}}},$$

where:

- $U$  is the convective heat transfer coefficient of the respective fluid. This coefficient is discussed in more detail in “Two-Phase Fluid Correlations” on page 1-554 and “Moist Air Correlations” on page 1-556.
- $F$  is the **Fouling factor** on the two-phase fluid or moist air side, respectively.
- $R_{\text{W}}$  is the **Thermal resistance through heat transfer surface**.
- $A_{\text{Th}}$  is the heat transfer surface area of the respective side of the exchanger.  $A_{\text{Th}}$  is the sum of the wall surface area,  $A_{\text{W}}$ , and the **Total fin surface area**,  $A_{\text{F}}$ :

$$A_{\text{Th}} = A_{\text{W}} + \eta_{\text{F}}A_{\text{F}},$$

where  $\eta_F$  is the **Fin efficiency**.

The total heat transfer rate between the fluids is the sum of the heat transferred in the three zones by the subcooled liquid ( $Q_L$ ), liquid-vapor mixture ( $Q_M$ ), and superheated vapor ( $Q_V$ ):

$$Q = \sum Q_Z = Q_L + Q_M + Q_V.$$

### Effectiveness by Flow Arrangement

The heat exchanger effectiveness varies according to its flow configuration and the mixing in each fluid. Below are the formulations for effectiveness calculated in the liquid and vapor zones for each configuration. The effectiveness is  $\varepsilon = 1 - \exp(-NTU)$  for all configurations in the mixture zone.

- When **Flow arrangement** is set to Parallel flow:

$$\varepsilon = \frac{1 - \exp[-NTU(1 + C_R)]}{1 + C_R}$$

- When **Flow arrangement** is set to Counter flow:

$$\varepsilon = \frac{1 - \exp[-NTU(1 - C_R)]}{1 - C_R \exp[-NTU(1 - C_R)]}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids unmixed:

$$\varepsilon = 1 - \exp\left\{\frac{NTU^{0.22}}{C_R} [\exp(-C_R NTU^{0.78}) - 1]\right\}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids mixed:

$$\varepsilon = \left[ \frac{1}{1 - \exp(-NTU)} + \frac{C_R}{1 - \exp(-C_R NTU)} - \frac{1}{NTU} \right]^{-1}$$

When one fluid is mixed and the other unmixed, the equation for effectiveness depends on the relative heat capacity rates of the fluids. When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to either Two-Phase Fluid 1 mixed & Moist Air 2 unmixed or Two-Phase Fluid 1 unmixed & Moist Air 2 mixed:

- When the fluid with  $C_{\max}$  is mixed and the fluid with  $C_{\min}$  is unmixed:

$$\varepsilon = \frac{1}{C_R} (1 - \exp\{-C_R [1 - \exp(-NTU)]\})$$

- When the fluid with  $C_{\min}$  is mixed and the fluid with  $C_{\max}$  is unmixed:

$$\varepsilon = 1 - \exp\left\{-\frac{1}{C_R} [1 - \exp(-C_R NTU)]\right\}$$

$C_R$  denotes the ratio between the heat capacity rates of the two fluids:

$$C_R = \frac{C_{\min}}{C_{\max}}.$$

## Condensation

On the moist air side, a layer of condensation may form on the heat transfer surface. This liquid layer can influence the amount of heat transferred between the moist air and two-phase fluid. The equations for E-NTU heat transfer above are given for *dry* heat transfer. To correct for the influence of condensation, the E-NTU equations are additionally calculated with the wet parameters listed below. Whichever of the two calculated heat flow rates results in a larger amount of moist air side cooling is used in heat calculations for each zone [1]. To use this method, the Lewis number is assumed to be close to 1 [1], which is true for moist air.

### E-NTU Quantities Used for Heat Transfer Rate Calculations

	Dry calculation	Wet calculation
Moist air zone inlet temperature	$T_{in,MA}$	$T_{in,wb,MA}$
Heat capacity rate	$\bar{m}_{MA}\bar{c}_{p,MA}$	$\bar{m}_{MA}\bar{c}_{eq,MA}$
Heat transfer coefficient	$U_{MA}$	$U_{MA}\frac{\bar{c}_{eq,MA}}{\bar{c}_{p,MA}}$

where:

- $T_{in,MA}$  is the moist air zone inlet temperature.
- $T_{in,wb,MA}$  is the moist air wet-bulb temperature associated with  $T_{in,MA}$ .
- $\bar{m}_{MA}$  is the dry air mass flow rate.
- $\bar{c}_{p,MA}$  is the moist air heat capacity per unit mass of dry air.
- $\bar{c}_{eq,MA}$  is the equivalent heat capacity. The *equivalent heat capacity* is the change in the moist air specific enthalpy (per unit of dry air),  $\bar{h}_{MA}$ , with respect to temperature at saturated moist air conditions:

$$\bar{c}_{eq,MA} = \left( \frac{\partial \bar{h}_{MA}}{\partial T_{MA}} \right)_s.$$

The mass flow rate of the condensed water vapor leaving the moist air mass flow depends on the relative humidity between the moist air inlet and the channel wall and the heat exchanger NTUs:

$$\dot{m}_{cond} = -\bar{m}_{MA}(W_{wall,MA} - W_{in,MA})\left(1 - e^{-NTU_{MA}}\right),$$

where:

- $W_{wall,MA}$  is the humidity ratio at the heat transfer surface.
- $W_{in,MA}$  is the humidity ratio at the moist air flow inlet.
- $NTU_{MA}$  is the number of transfer units on the moist air side, calculated as:

$$NTU_{MA} = \frac{U_{MA}\bar{c}_{eq,MA}A_{Th,MA}}{\bar{m}_{MA}\bar{c}_{eq,MA}}.$$

The energy flow associated with water vapor condensation is based on the difference between the vapor specific enthalpy,  $h_{water,wall}$ , and the specific enthalpy of vaporization,  $h_{fg}$ , for water:

$$\phi_{Cond} = \dot{m}_{cond}(h_{water, wall} - h_{fg}).$$

The condensate is assumed to not accumulate on the heat transfer surface, and does not influence geometric parameters such as tube diameter. The condensed water is assumed to be completely removed from the downstream moist air flow.

## Two-Phase Fluid Correlations

### Heat Transfer Coefficient

The convective heat transfer coefficient varies according to the fluid Nusselt number:

$$U = \frac{Nu k}{D_H},$$

where:

- $Nu$  is the zone mean Nusselt number, which depends on the flow regime.
- $k$  is the fluid phase thermal conductivity.
- $D_H$  is tube hydraulic diameter.

For turbulent flows in the subcooled liquid or superheated vapor zones, the Nusselt number is calculated with the Gnielinski correlation:

$$Nu = \frac{\frac{fD}{8}(Re - 1000)Pr}{1 + 12.7\sqrt{\frac{f}{8}}(Pr^{2/3} - 1)},$$

where:

- $Re$  is the fluid Reynolds number.
- $Pr$  is the fluid Prandtl number.

For turbulent flows in the liquid-vapor mixture zone, the Nusselt number is calculated with the Cavallini-Zecchin correlation:

$$Nu = \frac{a Re_{SL}^b Pr_{SL}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{Out} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{In} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) (x_{Out} - x_{In})}.$$

where:

- $Re_{SL}$  is the Reynolds number of the saturated liquid.
- $Pr_{SL}$  is the Prandtl number of the saturated liquid.
- $\rho_{SL}$  is the density of the saturated liquid.
- $\rho_{SV}$  is the density of the saturated vapor.
- $a = 0.05$ ,  $b = 0.8$ , and  $c = 0.33$ .

For laminar flows, the Nusselt number is set by the **Laminar flow Nusselt number** parameter.

For transitional flows, the Nusselt number is a blend between the laminar and turbulent Nusselt numbers.



### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** parameter is Colburn equation, the block calculates the Nusselt number for the subcooled liquid and superheated vapor zones by using the empirical Colburn equation

$$\text{Nu} = a\text{Re}^b\text{Pr}^c,$$

where  $a$ ,  $b$ , and  $c$  are values in the **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in liquid zone** and **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in vapor zone** parameters.

The block calculates the Nusselt number for liquid-vapor mixture zones by using the Cavallini-Zecchin equation with the variables in the **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in mixture zone** parameter.

### Pressure Loss

The pressure loss due to viscous friction varies depending on flow regime and configuration. The calculation uses the overall density, which is the total two-phase fluid mass divided by the total two-phase fluid volume.

For turbulent flows, when the Reynolds number is above the **Turbulent flow lower Reynolds number limit**, the pressure loss due to friction is calculated in terms of the Darcy friction factor. The pressure differential between port **A1** and the internal node I1 is:

$$p_{A1} - p_{I1} = \frac{f_{D,A}\dot{m}_{A1}|\dot{m}_{A1}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where:

- $\dot{m}_{A1}$  is the total flow rate through port **A1**.
- $f_{D,A}$  is the Darcy friction factor, according to the Haaland correlation:

$$f_{D,A1} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}_{A1}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2},$$

where  $\epsilon_R$  is the two-phase fluid pipe **Internal surface absolute roughness**. Note that the friction factor is dependent on the Reynolds number, and is calculated at both ports for each liquid.

- $L$  is the **Total length of each tube** on the two-phase fluid side.
- $L_{Add}$  is the two-phase fluid side **Aggregate equivalent length of local resistances**, which is the equivalent length of a tube that introduces the same amount of loss as the sum of the losses due to other local resistances in the tube.
- $A_{CS}$  is the tube cross-sectional area.

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{f_{D,B}\dot{m}_{B1}|\dot{m}_{B1}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where  $\dot{m}_{B1}$  is the total flow rate through port **B1**.

The Darcy friction factor at port **B1** is:

$$f_{D,B1} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}_{B1}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2}.$$

For laminar flows, when the Reynolds number is below the **Laminar flow upper Reynolds number limit**, the pressure loss due to friction is calculated in terms of the **Laminar friction constant for Darcy friction factor**,  $\lambda$ .  $\lambda$  is a user-defined parameter when **Tube cross-section** is set to **Generic**, otherwise, the value is calculated internally. The pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{\lambda \mu \dot{m}_{A1}}{2 \rho D_H^2 A_{CS}} \left( \frac{L + L_{\text{Add}}}{2} \right),$$

where  $\mu$  is the two-phase fluid dynamic viscosity. The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{\lambda \mu \dot{m}_{B1}}{2 \rho D_H^2 A_{CS}} \left( \frac{L + L_{\text{Add}}}{2} \right).$$

For transitional flows, the pressure differential due to viscous friction is a smoothed blend between the values for laminar and turbulent pressure losses.

#### Empirical Pressure Loss Formulation

When **Pressure loss model** is set to **Pressure loss coefficient**, the pressure losses due to viscous friction are calculated with an empirical pressure loss coefficient,  $\xi$ .

The pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{1}{2} \xi \frac{\dot{m}_{A1} |\dot{m}_{A1}|}{2 \rho A_{CS}^2}.$$

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{1}{2} \xi \frac{\dot{m}_{B1} |\dot{m}_{B1}|}{2 \rho A_{CS}^2}.$$

#### Moist Air Correlations

##### Heat Transfer Coefficient for Flows Inside One or More Tubes

When the moist air **Flow geometry** is set to **Flow inside one or more tubes**, the Nusselt number is calculated according to the Gnielinski correlation in the same manner as two-phase supercooled liquid or superheated vapor. See "Heat Transfer Coefficient" on page 1-554 for more information.

##### Heat Transfer Coefficient for Flows Across a Tube Bank

When the moist air **Flow geometry** is set to **Flow perpendicular to bank of circular tubes**, the Nusselt number is calculated based on the Hagen number,  $Hg$ , and depends on the **Tube bank grid arrangement** setting:

$$\text{Nu} = \begin{cases} 0.404 L q^{1/3} \left( \frac{\text{Re} + 1}{\text{Re} + 1000} \right)^{0.1}, & \text{Inline} \\ 0.404 L q^{1/3}, & \text{Staggered} \end{cases}$$

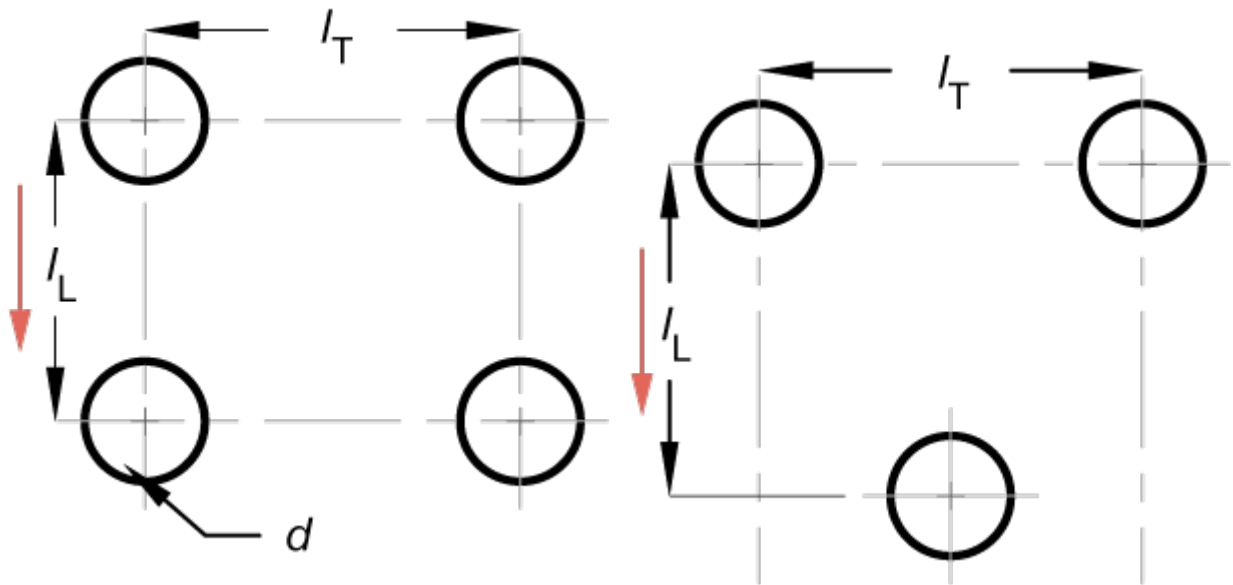
where:

$$Lq = \begin{cases} 1.18\text{Pr}\left(\frac{4l_T/\pi - D}{l_L}\right)\text{Hg}(\text{Re}), & \text{Inline} \\ 0.92\text{Pr}\left(\frac{4l_T/\pi - D}{l_D}\right)\text{Hg}(\text{Re}), & \text{Staggered with } l_L \geq D \\ 0.92\text{Pr}\left(\frac{4l_T l_L/\pi - D^2}{l_L l_D}\right)\text{Hg}(\text{Re}), & \text{Staggered with } l_L < D \end{cases}$$

- $D$  is the **Tube outer diameter**.
- $l_L$  is the **Longitudinal tube pitch (along flow direction)**, the distance between the tube centers along the flow direction. *Flow direction* refers to the moist air flow.
- $l_T$  is the **Transverse tube pitch (perpendicular to flow direction)**, shown in the figure below. The transverse pitch is the distance between the centers of the two-phase fluid tubing in one row.
- $l_D$  is the diagonal tube spacing, calculated as  $l_D = \sqrt{\left(\frac{l_T}{2}\right)^2 + l_L^2}$ .

For more information on calculating the Hagen number, see [6].

The longitudinal and transverse pitch distances are the same for both grid bank arrangement types.



### Cross-Section of Two-Phase Fluid Tubing with Pitch Measurements

#### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** is set to Colburn equation or when **Flow geometry** is set to Generic, the Nusselt number is calculated by the empirical Colburn equation:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c,$$

where  $a$ ,  $b$ , and  $c$  are the values defined in the **Coefficients [a, b, c] for  $a \cdot \text{Re}^b \cdot \text{Pr}^c$**  parameter.

### Pressure Loss for Flow Inside Tubes

When the moist air **Flow geometry** is set to **Flow inside one or more tubes**, the pressure loss is calculated in the same manner as for two-phase flows, with the respective Darcy friction factor, density, mass flow rates, and pipe lengths of the moist air side. See “Pressure Loss” on page 1-555 for more information.

### Pressure Loss for Flow Across Tube Banks

When the moist air **Flow geometry** is set to **Flow perpendicular to bank of circular tubes**, the Hagen number is used to calculate the pressure loss due to viscous friction. The pressure differential between port **A2** and internal node I2 is:

$$p_{A2} - p_{I2} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}),$$

where:

- $\mu_{MA}$  is the fluid dynamic viscosity.
- $N_R$  is the **Number of tube rows along flow direction**. This is the number of two-phase fluid tube rows along the moist air flow direction.

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}).$$

### Empirical Pressure Loss Formulation

When the **Pressure loss model** is set to **Euler number per tube row** or when **Flow geometry** is set to **Generic**, the pressure loss due to viscous friction is calculated with a pressure loss coefficient, in terms of the Euler number,  $Eu$ :

$$Eu = \frac{\xi}{N_R},$$

where  $\xi$  is the empirical pressure loss coefficient.

The pressure differential between port **A2** and internal node I2 is:

$$p_{A2} - p_{I2} = \frac{1}{2} N_R Eu \frac{\dot{m}_{A2} |\dot{m}_{A2}|}{2 \rho A_{CS}^2}.$$

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{1}{2} N_R Eu \frac{\dot{m}_{B2} |\dot{m}_{B2}|}{2 \rho A_{CS}^2}.$$

## Conservation Equations

### Two-Phase Fluid

The total mass accumulation rate in the two-phase fluid is defined as:

$$\frac{dM_{2P}}{dt} = \dot{m}_{A1} + \dot{m}_{B1},$$

where:

- $M_{2P}$  is the total mass of the two-phase fluid.
- $\dot{m}_{A1}$  is the mass flow rate of the fluid at port **A1**.
- $\dot{m}_{B1}$  is the mass flow rate of the fluid at port **B1**.

The flow is positive when flowing into the block through the port.

The energy conservation equation relates the change in specific internal energy to the heat transfer by the fluid:

$$M_{2P} \frac{du_{2P}}{dt} + u_{2P}(\dot{m}_{A1} + \dot{m}_{B1}) = \phi_{A1} + \phi_{B1} - Q,$$

where:

- $u_{2P}$  is the two-phase fluid specific internal energy.
- $\phi_{A1}$  is the energy flow rate at port **A1**.
- $\phi_{B1}$  is the energy flow rate at port **B1**.
- $Q$  is heat transfer rate, which is positive when leaving the two-phase fluid volume.

### Moist Air

There are three equations for mass conservation on the moist air side: one for the moist air mixture, one for condensed water vapor, and one for the trace gas.

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**Note** If **Trace gas model** is set to **None** in the Moist Air Properties (MA) block, the trace gas is not modeled in blocks in the moist air network. In the Condenser Evaporator (2P-MA) block, this means that the conservation equation for trace gas is set to 0.

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The moist air mixture mass accumulation rate accounts for the changes of the entire moist air mass flow through the exchanger ports and the condensation mass flow rate:

$$\frac{dM_{MA}}{dt} = \dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{\text{Cond}}.$$

The mass conservation equation for water vapor accounts for the water vapor transit through the moist air side and condensation formation:

$$\frac{dx_w}{dt} M_{MA} + x_w(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{\text{Cond}}) = \dot{m}_{w,A2} + \dot{m}_{w,B2} - \dot{m}_{\text{Cond}},$$

where:

- $x_w$  is the mass fraction of the vapor.  $\frac{dx_w}{dt}$  is the rate of change of this fraction.
- $\dot{m}_{w,A2}$  is the water vapor mass flow rate at port **A2**.
- $\dot{m}_{w,B2}$  is the water vapor mass flow rate at port **B2**.

- $\dot{m}_{Cond}$  is the rate of condensation.

The trace gas mass balance is:

$$\frac{dx_g}{dt} M_{MA} + x_g(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{Cond}) = \dot{m}_{g,A2} + \dot{m}_{g,B2},$$

where:

- $x_g$  is the mass fraction of the trace gas.  $\frac{dx_g}{dt}$  is the rate of change of this fraction.
- $\dot{m}_{g,A2}$  is the trace gas mass flow rate at port **A2**.
- $\dot{m}_{g,B2}$  is the trace gas mass flow rate at port **B2**.

Energy conservation on the moist air side accounts for the change in specific internal energy due to heat transfer and water vapor condensing out of the moist air mass:

$$M_{MA} \frac{du_{MA}}{dt} + u_{MA}(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{Cond}) = \phi_{A2} + \phi_{B2} + Q - \phi_{Cond},$$

where:

- $\phi_{A2}$  is the energy flow rate at port **A2**.
- $\phi_{B2}$  is the energy flow rate at port **B2**.
- $\phi_{Cond}$  is the energy flow rate due to condensation.

The heat transferred to or from the moist air,  $Q$ , is equal to the heat transferred from or to the two-phase fluid.

## Ports

### Conserving

#### **A1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **B1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **A2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

#### **B2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

## Output

### Z — Two-phase fluid zone length fractions

physical signal

Three-element vector of the zone length fractions in the two-phase fluid channel, returned as a physical signal. The vector takes the form [L, M, V], where L is the sub-cooled liquid, M is the liquid-vapor mixture, and V is the superheated vapor.

### W — Moist air condensation rate

physical signal

Water condensation rate in the moist air flow, returned as a physical signal. The condensate does not accumulate on the heat transfer surface.

## Parameters

### Configuration

#### Flow arrangement — Flow path alignment

Cross flow (default) | Parallel flow | Counter flow

Flow path alignment between the heat exchanger sides. The available flow arrangements are:

- Parallel flow. The flows run in the same direction.
- Counter flow. The flows run parallel to each other, in the opposite directions.
- Cross flow. The flows run perpendicular to each other.

#### Cross flow arrangement — Thermal mixing condition

Two-Phase Fluid 1 unmixed & Moist Air 2 mixed (default) | Both fluids unmixed | Two-phase fluid 1 mixed & Moist Air 2 unmixed | Both fluids mixed

Select whether each of the fluids can mix in its channel. Mixed flow means that the fluid is free to move in the transverse direction as it travels along the flow path. Unmixed flow means that the fluid is restricted to travel only along the flow path. For example, a side with fins is considered an unmixed flow.

### Dependencies

To enable this parameter, set **Flow arrangement** to Cross flow.

#### Thermal resistance through heat transfer surface — Wall thermal resistance

0 K/kW (default) | positive scalar

Thermal resistance of the wall that separates the two sides of the heat exchanger. The wall thermal resistance, wall fouling, and fluid convective heat transfer coefficient influence the amount of heat transferred between the flows.

#### Cross-sectional area at port A1 — Flow area at port A1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **A1**.

#### Cross-sectional area at port B1 — Flow area at port B1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **B1**.

**Cross-sectional area at port A2 — Flow area at port A2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air side port **A2**.

**Cross-sectional area at port B2 — Area normal to flow at port B2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air side port **B2**.

**Two-Phase Fluid 1**

**Number of tubes — Number of two-phase fluid tubes**

25 (default) | positive scalar

Number of two-phase fluid tubes.

**Total length of each tube — Total length of each two-phase fluid tube**

1 m (default) | positive scalar

Total length of each two-phase fluid tube.

**Tube cross section — Cross-sectional shape of a tube**

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of a tube. Use `Generic` to specify an arbitrary cross-sectional geometry.

This parameter specifies the cross-section of one tube.

**Tube inner diameter — Internal diameter of a single tube**

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to `Circular`.

**Tube width — Internal width of a single tube**

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to `Rectangular`.

**Tube height — Internal height of a single tube**

0.05 m (default) | positive scalar

Internal height of one tube. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.



**Dependencies**

To enable this parameter, set **Tube cross-section** to Rectangular.

**Annulus inner diameter (heat transfer surface) – Smaller diameter of annular cross-section**

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Annular.

**Annulus outer diameter – Larger diameter of annular cross-section**

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Annular.

**Cross-sectional area per tube – Internal area normal to flow in a single tube**

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss – Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Perimeter of tube cross-section for heat transfer – Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Pressure loss model – Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Pressure loss coefficient

Method of pressure loss calculation due to viscous friction. The settings are:

- **Pressure loss coefficient.** Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- **Correlation for flow inside tubes.** Use this setting to calculate the pressure loss based on the pipe flow correlation.

**Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$  – Empirical loss coefficient for all pressure losses in channel**

10 (default)

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. The loss coefficient is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2} \rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the two-phase fluid density, and  $v$  is the flow velocity.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Pressure loss coefficient.

**Aggregate equivalent length of local resistances – Combined length of all local resistances per tube**

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Correlation for flow inside tubes.

**Internal surface absolute roughness – Mean surface roughness height**

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.

**Dependencies**

To enable this parameter, set either:

- **Pressure loss model**
- **Heat transfer model**

to Correlation for flow inside tubes.

**Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow**

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number**, the flow regime is transitional.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter may also be known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Tube cross section** to Generic and **Pressure loss model** to Correlation for flow inside tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow inside tubes (default) | Colburn equation

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- Colburn equation. Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$ . In the liquid and vapor zones, the heat transfer coefficient is based on the Colburn equation. In the liquid-vapor mixture zone, the heat transfer coefficient is based on the Cavallini-Zecchin equation.
- Correlation for flow inside tubes. Use this setting to calculate the heat transfer coefficient for pipe flows. In the liquid and vapor zones, the heat transfer coefficient is calculated with the Gnielinski correlation. In the liquid-vapor mixture zone, the heat transfer coefficient is calculated with the Cavallini-Zecchin equation.

**Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in liquid zone – Colburn equation coefficients in liquid zone**

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which the block calculates by using the Colburn equation for each zone. The general form of the Colburn equation is:

$$Nu = aRe^bPr^c.$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Coefficients [a, b, c] for  $a \cdot \text{Re}^b \cdot \text{Pr}^c$  in mixture zone – Cavallini-Zecchin equation coefficients in mixture zone**

[.05, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients for the Cavallini-Zecchin equation. Each fluid zone has a distinct Nusselt number, which the block calculates in the mixture zone by using the Cavallini-Zecchin equation:

$$\text{Nu} = \frac{a \text{Re}_{\text{SL}}^b \text{Pr}_{\text{SL}}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) x_{\text{Out}} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) x_{\text{In}} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) (x_{\text{Out}} - x_{\text{In}})}$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Coefficients [a, b, c] for  $a \cdot \text{Re}^b \cdot \text{Pr}^c$  in vapor zone – Colburn equation coefficients in vapor zone**

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector that contains the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which the block calculates by using the Colburn equation for each zone. The general form of the Colburn equation is:

$$\text{Nu} = a \text{Re}^b \text{Pr}^c.$$

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

**Laminar flow Nusselt number – Ratio of convective to conductive heat transfer in the laminar flow regime**

3.66 (default) | positive scalar

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

**Dependencies**

To enable this parameter, set **Heat transfer coefficient model** to Correlation for flow inside tubes.

**Fouling factor – Additional thermal resistance due to fouling deposits**

0.1 m<sup>2</sup>\*K/kW (default) | positive scalar

Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time. However, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area – Total heat transfer surface area of fins**

0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency — Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial fluid energy specification — Initial state of the two-phase fluid**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Quantity used to describe the initial state of the fluid.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- **Temperature** — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- **Vapor quality** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Vapor void fraction** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

**Initial two-phase fluid pressure — Fluid pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Fluid pressure at the start of the simulation.

**Initial two-phase fluid temperature — Temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Temperature.

**Initial two-phase fluid vapor quality — Vapor mass fraction at start of simulation**

0.5 (default) | positive scalar in the range [0,1] | two-element vector

Vapor mass fraction in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial vapor quality in the channel. A vector value represents the initial vapor quality at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

**Initial two-phase fluid vapor void fraction — Vapor volume fraction at start of simulation**

0.5 (default) | positive scalar in the range [0,1] | two-element vector

Vapor volume fraction in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial void fraction in the channel. A vector value represents the initial void fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

**Initial two-phase fluid specific enthalpy — Enthalpy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Enthalpy per unit mass in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific enthalpy in the channel. A vector value represents the initial specific enthalpy at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

**Initial two-phase fluid specific internal energy — Internal energy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Internal energy per unit mass in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific internal energy in the channel. A vector value represents the initial specific internal energy at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

## Moist Air 2

### Flow geometry — Moist air flow configuration

Flow perpendicular to bank of circular tubes (default) | Flow inside one or more tubes | Generic

Moist air flow path. The flow can run externally over a set of tubes or internal to a tube or set of tubes. You can also specify a generic parameterization based on empirical values.

### Number of tubes — Number of moist air tubes

25 (default) | positive scalar

Number of moist air tubes. More tubes result in higher pressure losses due to viscous friction, but a larger amount of surface area for heat transfer.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

### Total length of each tube — Total length of each moist air tube

1 m (default) | positive scalar

Total length of each moist air tube.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

### Tube cross section — Cross-sectional shape of a tube

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of one tube. Set to Generic to specify an arbitrary cross-sectional geometry.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

### Tube inner diameter — Internal diameter of a single tube

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Circular.

### Tube width — Internal width of a single tube

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Tube height — Internal height of a single tube**

0.05 m (default) | positive scalar

Internal height of one tube cross-section. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Annulus inner diameter (heat transfer surface) — Smaller diameter of annular cross-section**

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Annular.

**Annulus outer diameter — Larger diameter of annular cross-section**

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Annular.

**Cross-sectional area per tube — Internal flow area in each tube**

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss — Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.



**Perimeter of tube cross-section for heat transfer – Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Pressure loss model – Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Euler number per tube row | Pressure loss coefficient | Correlation for flow over tube bank

Method of pressure loss calculation due to viscous friction. Different models are available for different flow configurations. The settings are:

- Correlation for flow inside tubes. Use this setting to calculate the pressure loss with the Haaland correlation.
- Pressure loss coefficient. Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- Euler number per tube row. Use this setting to calculate the pressure loss based on an empirical Euler number.
- Correlation for flow over tube bank. Use this setting to calculate the pressure loss based on the Hagen number.

The pressure loss models available depend on the **Flow geometry** setting.

**Dependencies**

When **Flow geometry** is set to Flow inside one or more tubes, **Pressure loss model** can be set to either:

- Pressure loss coefficient.
- Correlation for flow inside tubes.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, **Pressure loss model** can be set to either:

- Correlation for flow over tube bank.
- Euler number per tube row.

When **Flow geometry** is set to Generic, the **Pressure loss model** parameter is disabled. Pressure loss is calculated empirically with the **Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$**  parameter.

**Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$  – Empirical loss coefficient for all pressure losses in the channel**

10 (default) | positive scalar

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. The pressure loss coefficient is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2}\rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the two-phase fluid density, and  $v$  is the flow velocity.

#### Dependencies

To enable this parameter, set either:

- **Flow geometry** to Generic.
- **Pressure loss model** to Pressure loss coefficient.

#### Aggregate equivalent length of local resistances – Combined length of all local resistances per tube

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

#### Dependencies

To enable this parameter, set **Pressure loss model** to Correlations for flow inside tubes.

#### Internal surface absolute roughness – Mean surface roughness height

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.

#### Dependencies

To enable this parameter, set either:

- **Pressure loss model**
- **Heat transfer coefficient model**

to Correlation for flow inside tubes.

#### Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number limit**, the flow regime is transitional.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional between the laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter is also known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Correlation for flow inside tubes, **Tube cross section** to Generic, and **Pressure loss model** to Correlation for flow inside tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow over tube bank (default) | Colburn equation | Correlation for flow inside tubes

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- Colburn equation. Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$  of the Colburn equation.
- Correlation for flow over tube bank. Use this setting to calculate the heat transfer coefficient based on the tube bank correlation using the Hagen number.
- Correlation for flow inside tubes. Use this setting to calculate the heat transfer coefficient for pipe flows with the Gnielinski correlation.

**Dependencies**

To enable this parameter, set **Flow geometry** to either:

- Flow perpendicular to bank of circular tubes.
- Flow inside one or more tubes.

**Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  – Colburn equation coefficients**

[0.023, 0.8, 0.33] (default) | three-element vector

Three-element vector containing the empirical coefficients of the Colburn equation. The Colburn equation is a formulation for calculating the Nusselt Number. The general form of the Colburn equation is:

$$Nu = aRe^bPr^c.$$

When the **Heat transfer coefficient model** is set to **Colburn equation** and **Flow geometry** is set to Flow inside one or more tubes, or **Flow geometry** is set to Generic, the default Colburn equation is:

$$\text{Nu} = 0.023\text{Re}^{0.8}\text{Pr}^{1/3}.$$

When the **Heat transfer coefficient model** is set to **Colburn equation** and **Flow geometry** is set to Flow perpendicular to bank of circular tubes, the default Colburn equation is:

$$\text{Nu} = 0.27\text{Re}^{0.63}\text{Pr}^{0.36}.$$

### Dependencies

To enable this parameter, set:

**1 Flow geometry** to either:

- Flow inside one or more tubes
- Flow perpendicular to bank of circular tubes

and **Heat transfer coefficient model** to Colburn equation.

**2 Flow geometry** to Generic.

### Laminar flow Nusselt number – Ratio of convective to conductive heat transfer in laminar flow regime

3.66 (default) | positive scalar

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes, **Tube cross-section** to Generic, and **Heat transfer parameterization** to Correlation for flow inside tubes.

### Tube bank grid arrangement – Geometrical placement of tube rows in the bank

Inline (default) | Staggered

Alignment of tubes in a tube bank. Rows are either in line with their neighbors, or staggered.

- **Inline:** All tube rows are located directly behind each other.
- **Staggered:** Tubes of the one tube row are located at the gap between tubes of the previous tube row.

Tube alignment influences the Nusselt number and the heat transfer rate.

### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

### Number of tube rows along flow direction – Number of tube rows in tube bank

5 (default) | positive scalar

Number of two-phase fluid tube rows in a tube bank. The rows are aligned with the direction of moist air flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Number of tube segments in each tube row – Number of two-phase fluid tubes in each row of the tube bank**

5 (default) | positive scalar

Number of two-phase fluid tubes in each row of a tube bank. This measurement is perpendicular to the moist air flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Length of each tube segment in a tube row – Length of each two-phase fluid tube**

1 m (default) | positive scalar

Length of each two-phase fluid tube that spans a tube row. All tubes in a tube bank are the same length.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Tube outer diameter – Outer diameter of a single two-phase fluid tube**

0.05 m (default) | positive scalar

Outer diameter of a two-phase fluid tube. The cross-section is uniform along a tube and so the diameter is constant throughout. This value influences the losses in the flow across a tube bank due to viscous friction.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Longitudinal tube pitch (along flow direction) – Center-to-center distance between two-phase fluid tube rows**

0.15 m (default) | positive scalar

Distance between tube centers of the two-phase fluid tubes, aligned with the direction of flow of the moist air.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Transverse tube pitch (perpendicular to flow direction) – Center-to-center distance between two-phase fluid tubes in a row**

0.15 m (default) | positive scalar

Distance between the tube centers in a row of two-phase fluid tubes. This measurement is perpendicular to the moist air flow direction. See “Heat Transfer Coefficient for Flows Across a Tube Bank” on page 1-556 for more information.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

#### Euler number per tube row, $\Delta p / (N \cdot 0.5 \cdot \rho \cdot v^2)$ – Euler number for each row of the tube bank

10 (default) | positive scalar

Empirical coefficient for pressure drop across one tube row. The Euler number is the ratio between pressure drop and fluid momentum:

$$Eu = \frac{\Delta p}{N \frac{1}{2} \rho v^2},$$

where  $N$  is the **Number of tube rows along flow direction**,  $\Delta p$  is the pressure drop,  $\rho$  is the moist air mixture density, and  $v$  is the flow velocity.

Each tube row is located in a plane perpendicular to the moist air flow.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes and **Pressure loss model** to Euler number per tube row.

#### Minimum free-flow area – Smallest total flow area between inlet and outlet

0.01 m<sup>2</sup> (default) | positive scalar

Smallest total flow area between inlet and outlet. If the channel is a collection of ducts, tubes, slots, or grooves, the minimum free-flow area is the sum of the smallest areas.

#### Dependencies

To enable this parameter, set **Flow geometry** to Generic.

#### Heat transfer surface area without fins – Total area of the heat transfer surface excluding fins

2 m<sup>2</sup> (default) | positive scalar

Total area of the heat transfer surface, excluding fins.

#### Dependencies

To enable this parameter, set **Flow geometry** to Generic.

#### Moist air volume inside heat exchanger – Total volume of moist air in the heat exchanger

0.05 m<sup>3</sup> (default) | positive scalar

Total volume of moist air in the heat exchanger.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Fouling factor – Additional thermal resistance due to fouling deposits**

0.1 m<sup>2</sup>\*K/kW (default) | positive scalar

Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time. However, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area – Total heat transfer surface area of all fins**

0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency – Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial moist air pressure – Moist air pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Moist air pressure at the start of the simulation.

**Initial moist air temperature – Temperature at the start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the moist air fluid channel at the start of the simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Initial moisture specification – Moisture specification**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Moisture specification, which can be set as relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

**Initial moist air relative humidity – Relative humidity at the start of simulation**

0.5 (default) | positive scalar in the range of [0,1] | two-element vector

Relative humidity in the moist air channel at the start of the simulation. The relative humidity is the ratio of the water vapor partial pressure to the water vapor saturation pressure, or the ratio of the water vapor mole fraction to the water vapor mole fraction at saturation.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial relative humidity in the channel. A vector value represents the initial relative humidity at the inlet

and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Relative humidity.

**Initial moist air specific humidity — Specific humidity at the start of simulation**

0.01 (default) | positive scalar in the range of [0,1] | two-element vector

Specific humidity in the moist air channel at the start of simulation. The specific humidity is the mass fraction of water vapor to the combined total mass of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific humidity in the channel. A vector value represents the initial specific humidity at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Specific humidity.

**Initial moist air water vapor mole fraction — Mole fraction of water vapor at the start of simulation**

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Mole fraction of the water vapor in the moist air channel at the start of simulation. The water vapor mole fraction is relative to the combined molar quantity of water vapor, trace species, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial vapor mole fraction in the channel. A vector value represents the initial vapor mole fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Mole fraction.

**Initial moist air humidity ratio — Humidity ratio at the start of simulation**

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Humidity ratio in the moist air channel at the start of the simulation. The humidity ratio is the ratio of the mass of water vapor to the mass of dry air and trace gas.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial humidity ratio in the channel. A vector value represents the initial humidity ratio at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Humidity ratio.

**Initial trace gas specification — Measurement type of trace gas**

Mass fraction (default) | Mole fraction

Measurement type of trace gas.



**Initial moist air trace gas mass fraction — Amount of trace gas in the moist air channel**

0.001 (default) | positive scalar in the range of [0,1] | two-element vector

Amount of trace gas in the moist air channel by mass fraction at the start of the simulation. The mass fraction is relative to the combined total mass of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean trace gas mass fraction in the channel. A vector value represents the initial trace gas mass fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Initial trace gas specification** to Mass fraction.

**Initial moist air trace gas mole fraction — Mole fraction of trace gas at the start of simulation**

0.001 (default) | positive scalar in the range of [0,1] | two-element vector

Amount of trace gas in the moist air channel by mole fraction at the start of the simulation. The mole fraction is relative to the combined molar total of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean trace gas mole fraction in the channel. A vector value represents the initial trace gas mole fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Initial trace gas specification** to Mole fraction.

**Relative humidity at saturation — Relative humidity point of condensation**

1 (default) | positive scalar in the range of [0,1]

Relative humidity point of condensation. Condensation occurs above this value. A value greater than 1 indicates a supersaturated vapor.

## Version History

Introduced in R2019a

## References

- [1] *2013 ASHRAE Handbook - Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013.
- [2] Braun, J. E., S. A. Klein, and J. W. Mitchell. "Effectiveness Models for Cooling Towers and Cooling Coils." *ASHRAE Transactions* 95, no. 2, (June 1989): 164-174.

- [3] Çengel, Yunus A. *Heat and Mass Transfer: A Practical Approach*. 3rd ed, McGraw-Hill, 2007.
- [4] Ding, X., Epe J.P., Lebrun, J., Wasacz, M. "Cooling Coil Model to be Used in Transient and/or Wet Regimes. Theoretical Analysis and Experimental Validation." *Proceedings of the Third International Conference on System Simulation in Buildings* (1990): 405-411.
- [5] Mitchell, John W., and James E. Braun. *Principles of Heating, Ventilation, and Air Conditioning in Buildings*. Wiley, 2013.
- [6] Shah, R. K., and Dušan P. Sekulić. *Fundamentals of Heat Exchanger Design*. John Wiley & Sons, 2003.
- [7] White, Frank M. *Fluid Mechanics*. 6th ed, McGraw-Hill, 2009.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

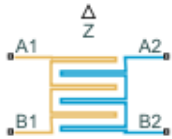
### **See Also**

Thermostatic Expansion Valve (2P) | Condenser Evaporator (TL-2P) | Heat Exchanger (TL-MA) | E-NTU Heat Transfer | Heat Exchanger (G-TL) | Heat Exchanger (TL-TL)

## Condenser Evaporator (TL-2P)

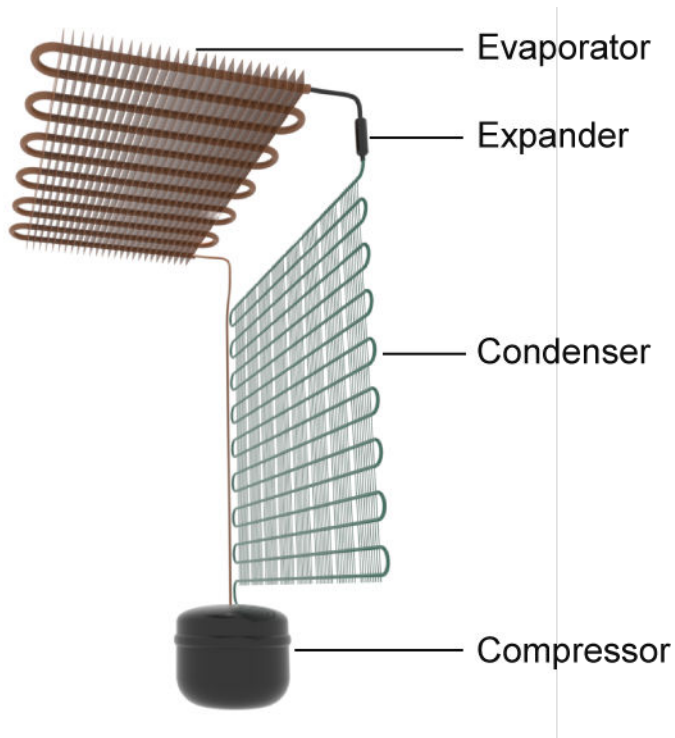
Models heat exchange between a thermal liquid network and a network that can undergo phase change

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Condenser Evaporator (TL-MA) block models a heat exchanger with one thermal liquid network, which flows between ports **A1** and **B1**, and one two-phase fluid network, which flows between ports **A2** and **B2**. The heat exchanger can act as a condenser or as an evaporator. The fluid streams can be aligned in parallel, counter, or cross-flow configurations.

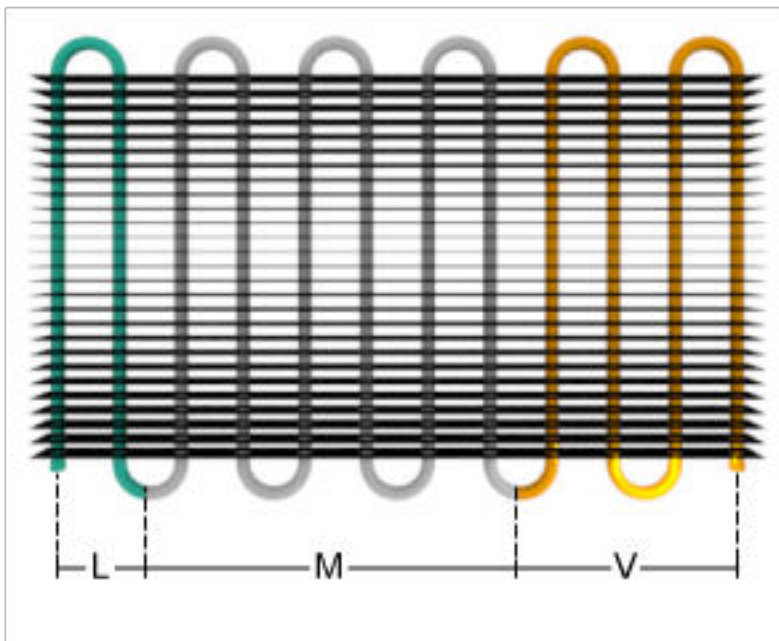


### Example Heat Exchanger for Refrigeration Applications

You can model the thermal liquid side as flow within tubes, flow around the two-phase fluid tubing, or by an empirical, generic parameterization.

The block uses the Effectiveness-NTU (E-NTU) method to model heat transfer through the shared wall. Fouling on the exchanger walls, which increases thermal resistance and reduces the heat exchange between the two fluids, is also modeled. You can also optionally model fins on both the thermal liquid and two-phase fluid sides. Pressure loss due to viscous friction on both sides of the exchanger can be modeled analytically or by generic parameterization, which you can use to tune to your own data.

You can model the two-phase fluid side as flow within a tube or a set of tubes. The two-phase fluid tubes use a boundary-following model to track the sub-cooled liquid (L), vapor-liquid mixture (M), and super-heated vapor (V) in three zones. The relative amount of space a zone occupies in the system is called a *zone length fraction* within the system.



### **Zone Length Fractions in the Two-Phase Fluid Piping**

The sum of the zone length fractions in the two-phase fluid tubing equals 1. Port **Z** returns the zone length fractions as a vector of physical signals for each of the three phases: [L, M, V].

### **Heat Exchanger Configuration**

The heat exchanger effectiveness is based on the selected heat exchanger configuration, the fluid properties in each phase, the tube geometry and flow configuration on each side of the exchanger, and the usage and size of fins.

**Flow Arrangement**

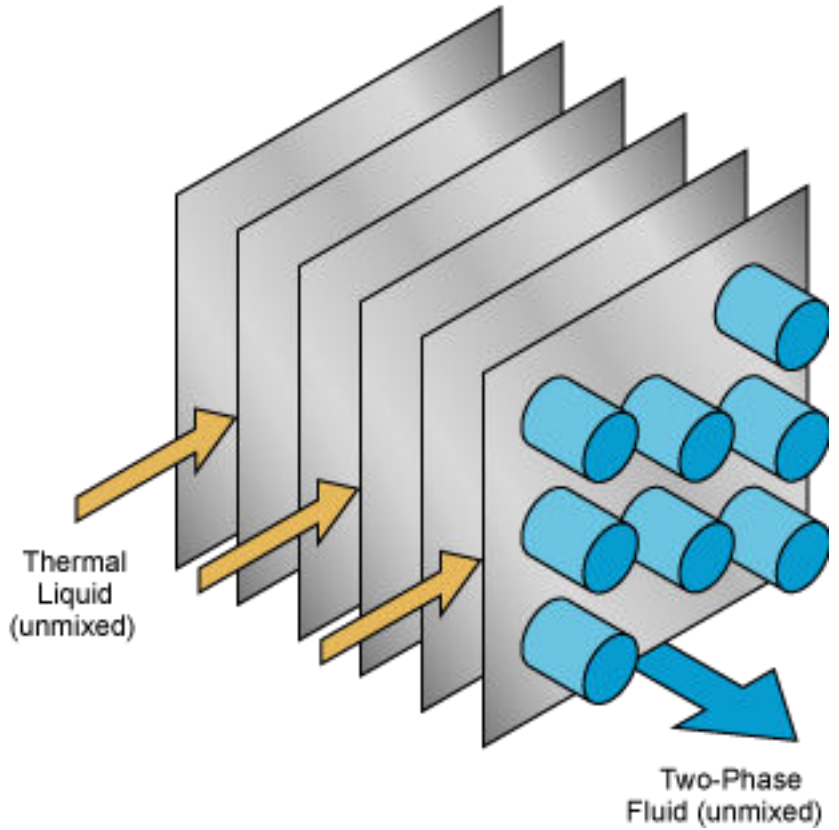
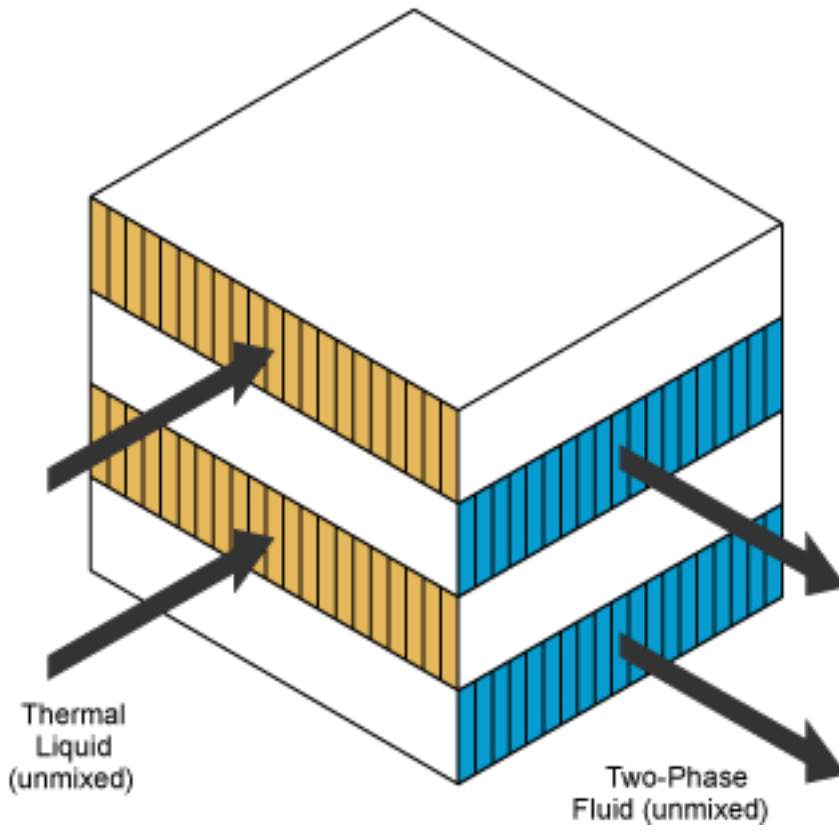
The **Flow arrangement** parameter assigns the relative flow paths between the two sides:

- Parallel flow indicates the fluids are moving in the same direction.
- Counter flow indicates the fluids are moving in parallel, but opposite directions.
- Cross flow indicates the fluids are moving perpendicular to each other.

**Thermal Mixing**

When **Flow arrangement** is set to Cross flow, use the **Cross flow arrangement** parameter to indicate whether the two-phase fluid or thermal liquid flows are separated into multiple paths by baffles or walls. Without these separations, the flow can mix freely and is considered *mixed*. Both fluids, one fluid, or neither fluid can be mixed in the cross-flow arrangement. Mixing homogenizes the fluid temperature along the direction of flow of the second fluid, and varies perpendicular to the second fluid flow.

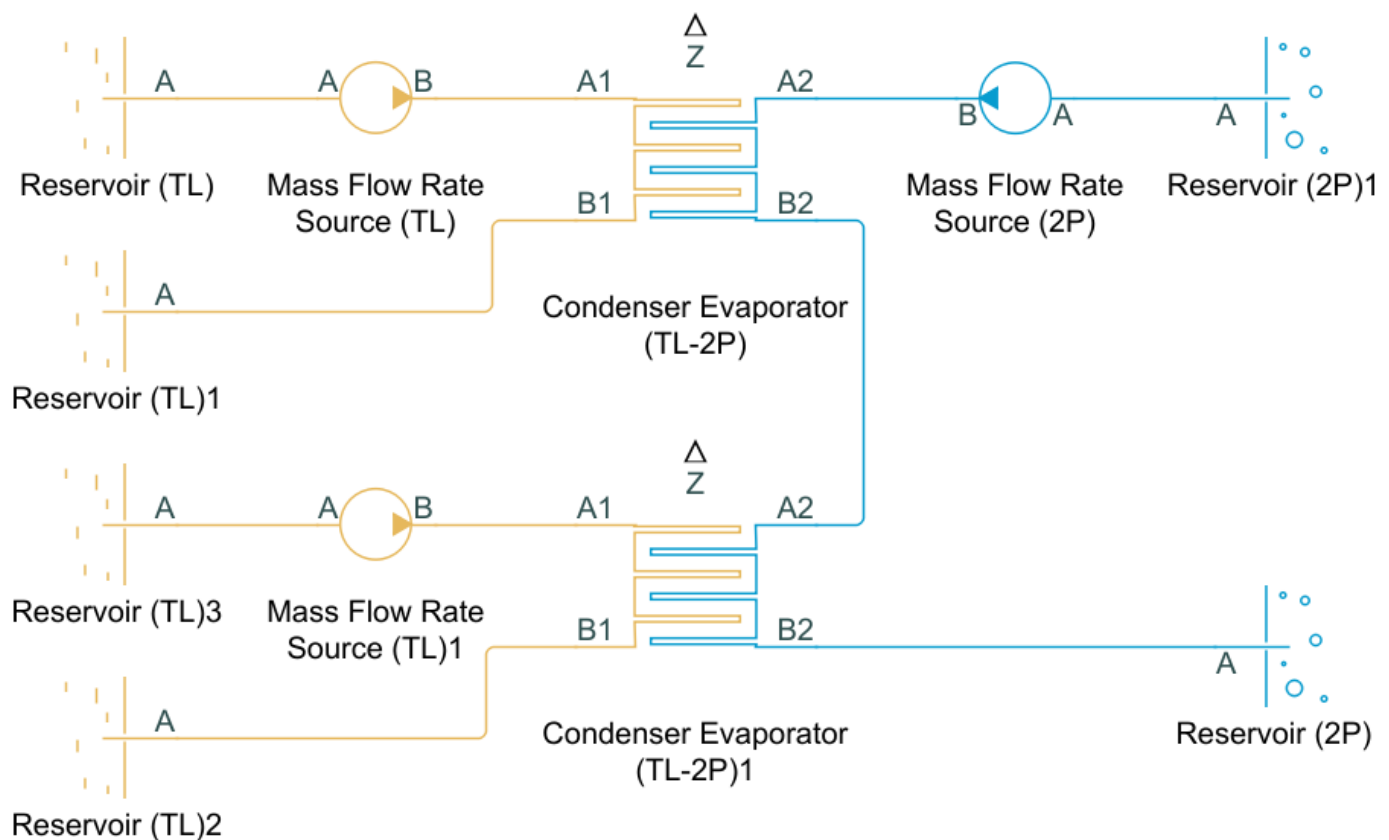
Unmixed flows vary in temperature both along and perpendicular to the flow path of the second fluid.



Note that the flow direction during simulation does not impact the selected flow arrangement setting. The ports on the block do not reflect the physical positions of the ports in the physical heat exchanger system.

All flow arrangements are single-pass, which means that the fluids do not make multiple turns in the exchanger for additional points of heat transfer. To model a multi-pass heat exchanger, you can arrange multiple Condenser Evaporator (TL-2P) blocks in series or in parallel.

For example, to achieve a two-pass configuration on the two-phase fluid side and a single-pass configuration on the thermal liquid side, you can connect the two-phase fluid sides in series and the thermal liquid sides to the same input in parallel (such as two Mass Flow Rate Source blocks with half of the total mass flow rate), as shown below.



### Flow Geometry

The **Flow geometry** parameter sets the thermal liquid flow arrangement as either inside a tube or set of tubes, or perpendicular to a tube bank. You can also specify an empirical, generic configuration. The two-phase fluid always flows inside a tube or set of tubes.

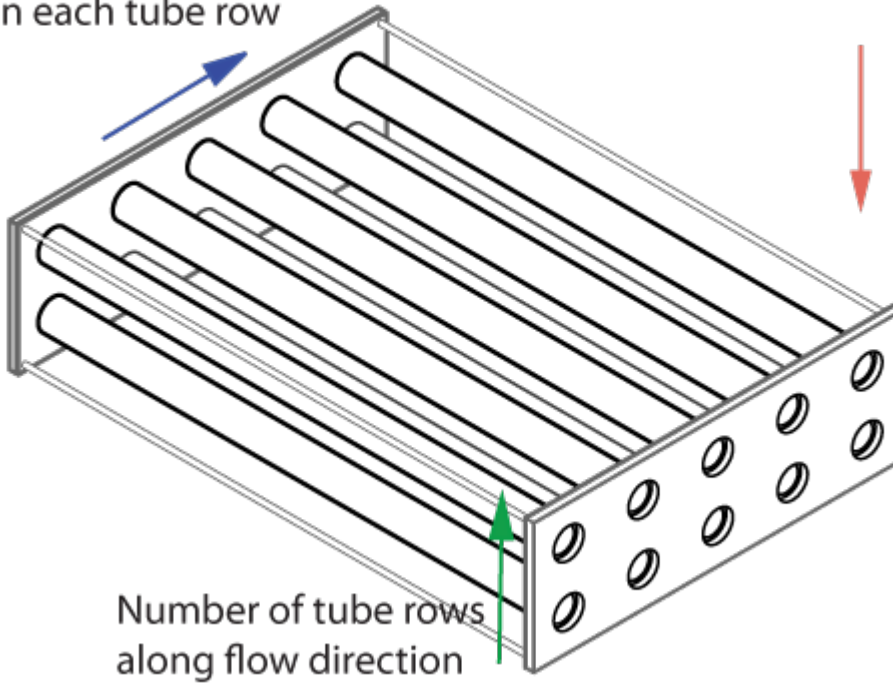
When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, use the **Tube bank grid arrangement** parameter to define the two-phase fluid tube bank alignment as either Inline or Staggered. The red, downward-pointing arrow indicates the direction of thermal liquid flow. The Inline figure also shows the **Number of tube rows along flow direction** and the **Number of tube segments in each tube row** parameters. Here, *flow direction* refers to the

thermal liquid flow, and *tube* refers to the two-phase fluid tubing. The **Length of each tube segment in a tube row** parameter is indicated in the Staggered figure.

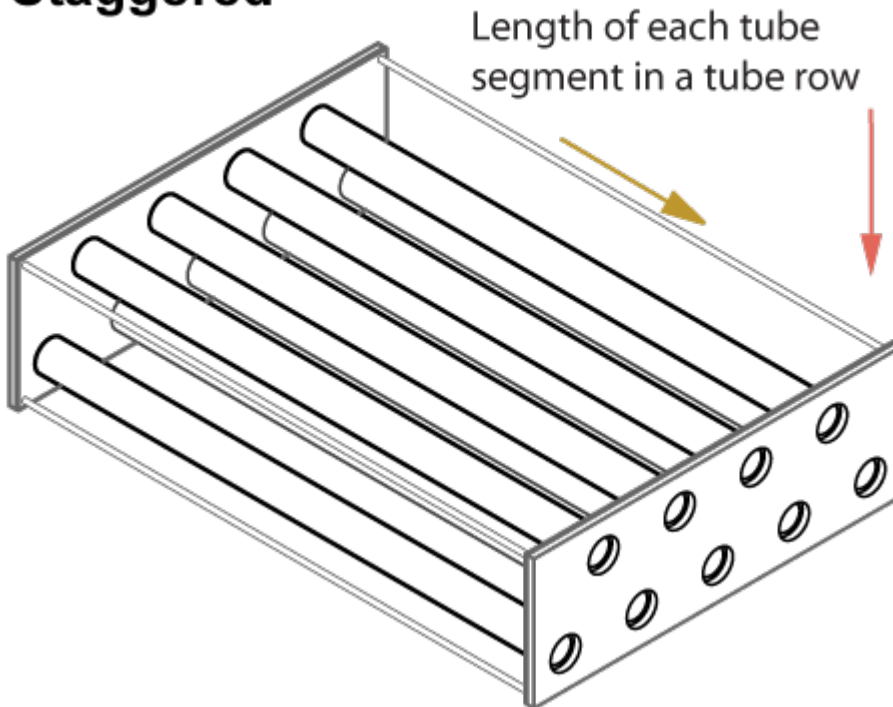


Number of tube segments  
in each tube row

### Inline



### Staggered



## Fins

The heat exchanger configuration is without fins when the **Total fin surface area** parameter is set to 0 m<sup>2</sup>. Fins introduce additional surface area for additional heat transfer. Each fluid side has a separate fin area.

## Effectiveness-NTU Heat Transfer

The heat transfer rate is calculated for each fluid phase. In accordance with the three fluid zones that occur on the two-phase fluid side of the heat exchanger, the heat transfer rate is calculated in three sections.

The heat transfer in a zone is calculated as:

$$Q_{zone} = \epsilon C_{\text{Min}}(T_{\text{In},2\text{P}} - T_{\text{In},\text{TL}}),$$

where:

- $C_{\text{Min}}$  is the lesser of the heat capacity rates of the two fluids in that zone. The heat capacity rate is the product of the fluid specific heat,  $c_p$ , and the fluid mass flow rate.  $C_{\text{Min}}$  is always positive.
- $T_{\text{In},2\text{P}}$  is the zone inlet temperature of the two-phase fluid.
- $T_{\text{In},\text{TL}}$  is the zone inlet temperature of the thermal liquid.
- $\epsilon$  is the heat exchanger effectiveness.

Effectiveness is a function of the heat capacity rate and the number of transfer units,  $NTU$ , and also varies based on the heat exchanger flow arrangement, which is discussed in more detail in “Effectiveness by Flow Arrangement” on page 1-589. The  $NTU$  is calculated as:

$$NTU = \frac{z}{C_{\text{Min}}R},$$

where:

- $z$  is the individual zone length fraction.
- $R$  is the total thermal resistance between the two flows, due to convection, conduction, and any fouling on the tube walls:

$$R = \frac{1}{U_{2\text{P}}A_{\text{Th},2\text{P}}} + \frac{F_{2\text{P}}}{A_{\text{Th},2\text{P}}} + R_{\text{W}} + \frac{F_{\text{TL}}}{A_{\text{Th},\text{TL}}} + \frac{1}{U_{\text{TL}}A_{\text{Th},\text{TL}}},$$

where:

- $U$  is the convective heat transfer coefficient of the respective fluid. This coefficient is discussed in more detail in “Two-Phase Fluid Correlations” on page 1-590 and “Thermal Liquid Correlations” on page 1-592.
- $F$  is the **Fouling factor** on the two-phase fluid or thermal liquid side, respectively.
- $R_{\text{W}}$  is the **Thermal resistance through heat transfer surface**.
- $A_{\text{Th}}$  is the heat transfer surface area of the respective side of the exchanger.  $A_{\text{Th}}$  is the sum of the wall surface area,  $A_{\text{W}}$ , and the **Total fin surface area**,  $A_{\text{F}}$ :

$$A_{\text{Th}} = A_{\text{W}} + \eta_{\text{F}}A_{\text{F}},$$

where  $\eta_F$  is the **Fin efficiency**.

The total heat transfer rate between the fluids is the sum of the heat transferred in the three zones by the subcooled liquid ( $Q_L$ ), liquid-vapor mixture ( $Q_M$ ), and superheated vapor ( $Q_V$ ):

$$Q = \sum Q_Z = Q_L + Q_M + Q_V.$$

### Effectiveness by Flow Arrangement

The heat exchanger effectiveness varies according to its flow configuration and the mixing in each fluid. Below are the formulations for effectiveness calculated in the liquid and vapor zones for each configuration. The effectiveness is  $\varepsilon = 1 - \exp(-NTU)$  for all configurations in the mixture zone.

- When **Flow arrangement** is set to Parallel flow:

$$\varepsilon = \frac{1 - \exp[-NTU(1 + C_R)]}{1 + C_R}$$

- When **Flow arrangement** is set to Counter flow:

$$\varepsilon = \frac{1 - \exp[-NTU(1 - C_R)]}{1 - C_R \exp[-NTU(1 - C_R)]}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids unmixed:

$$\varepsilon = 1 - \exp\left\{\frac{NTU^{0.22}}{C_R} \left[\exp(-C_R NTU^{0.78}) - 1\right]\right\}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids mixed:

$$\varepsilon = \left[ \frac{1}{1 - \exp(-NTU)} + \frac{C_R}{1 - \exp(-C_R NTU)} - \frac{1}{NTU} \right]^{-1}$$

When one fluid is mixed and the other unmixed, the equation for effectiveness depends on the relative heat capacity rates of the fluids. When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to either Thermal Liquid 1 mixed & Two-Phase Fluid 2 unmixed or Thermal Liquid 1 unmixed & Two-Phase Fluid 2 mixed:

- When the fluid with  $C_{\max}$  is mixed and the fluid with  $C_{\min}$  is unmixed:

$$\varepsilon = \frac{1}{C_R} (1 - \exp\{-C_R [1 - \exp(-NTU)]\})$$

- When the fluid with  $C_{\min}$  is mixed and the fluid with  $C_{\max}$  is unmixed:

$$\varepsilon = 1 - \exp\left\{-\frac{1}{C_R} [1 - \exp(-C_R NTU)]\right\}$$

$C_R$  denotes the ratio between the heat capacity rates of the two fluids:

$$C_R = \frac{C_{\min}}{C_{\max}}.$$

## Two-Phase Fluid Correlations

### Heat Transfer Coefficient

The convective heat transfer coefficient varies according to the fluid Nusselt number:

$$U = \frac{Nu k}{D_H},$$

where:

- $Nu$  is the zone mean Nusselt number, which depends on the flow regime.
- $k$  is the fluid phase thermal conductivity.
- $D_H$  is tube hydraulic diameter.

For turbulent flows in the subcooled liquid or superheated vapor zones, the Nusselt number is calculated with the Gnielinski correlation:

$$Nu = \frac{\frac{f_D}{8}(Re - 1000)Pr}{1 + 12.7\sqrt{\frac{f_D}{8}}(Pr^{2/3} - 1)},$$

where:

- $Re$  is the fluid Reynolds number.
- $Pr$  is the fluid Prandtl number.

For turbulent flows in the liquid-vapor mixture zone, the Nusselt number is calculated with the Cavallini-Zecchin correlation:

$$Nu = \frac{a Re_{SL}^b Pr_{SL}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{Out} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) x_{In} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{SL}}{\rho_{SV}}} - 1 \right) (x_{Out} - x_{In})}.$$

where:

- $Re_{SL}$  is the Reynolds number of the saturated liquid.
- $Pr_{SL}$  is the Prandtl number of the saturated liquid.
- $\rho_{SL}$  is the density of the saturated liquid.
- $\rho_{SV}$  is the density of the saturated vapor.
- $a = 0.05$ ,  $b = 0.8$ , and  $c = 0.33$ .

For laminar flows, the Nusselt number is set by the **Laminar flow Nusselt number** parameter.

For transitional flows, the Nusselt number is a blend between the laminar and turbulent Nusselt numbers.

### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** parameter is set to Colburn equation, the Nusselt number for the subcooled liquid and superheated vapor zones is calculated by the empirical the Colburn equation:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c,$$

where  $a$ ,  $b$ , and  $c$  are defined in the **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in liquid zone** and **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in vapor zone** parameters.

The Nusselt number for liquid-vapor mixture zones is calculated with the Cavallini-Zecchin equation, with the coefficients specified in the **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$  in mixture zone** parameter.

### Pressure Loss

The pressure loss due to viscous friction varies depending on flow regime and configuration. The calculation uses the overall density, which is the total two-phase fluid mass divided by the total two-phase fluid volume.

For turbulent flows, when the Reynolds number is above the **Turbulent flow lower Reynolds number limit**, the pressure loss due to friction is calculated in terms of the Darcy friction factor. The pressure differential between port **A2** and the internal node I2 is:

$$p_{A2} - p_{I2} = \frac{f_{D,A}\dot{m}_{A2}|\dot{m}_{A2}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where:

- $\dot{m}_{A2}$  is the total flow rate through port **A2**.
- $f_{D,A}$  is the Darcy friction factor, according to the Haaland correlation:

$$f_{D,A2} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}_{A2}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2},$$

where  $\epsilon_R$  is the two-phase fluid pipe **Internal surface absolute roughness**. Note that the friction factor is dependent on the Reynolds number, and is calculated at both ports for each liquid.

- $L$  is the **Total length of each tube** on the two-phase fluid side.
- $L_{Add}$  is the two-phase fluid **Aggregate equivalent length of local resistances**, which is the equivalent length of a tube that introduces the same amount of loss as the sum of the losses due to other local resistances in the tube.
- $A_{CS}$  is the total tube cross-sectional area.

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{f_{D,B}\dot{m}_{B2}|\dot{m}_{B2}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where  $\dot{m}_{B2}$  is the total flow rate through port **B2**.

The Darcy friction factor at port **B2** is:

$$f_{D,B2} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}_{B2}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2}.$$

For laminar flows, when the Reynolds number is below the **Laminar flow upper Reynolds number limit**, the pressure loss due to friction is calculated in terms of the **Laminar friction constant for**

**Darcy friction factor**,  $\lambda$ .  $\lambda$  is a user-defined parameter when **Tube cross-section** is set to **Generic**, otherwise, the value is calculated internally. The pressure differential between port **A2** and internal node I2 is:

$$p_{A2} - p_{I2} = \frac{\lambda \mu \dot{m}_{A2}}{2\rho D_H^2 A_{CS}} \left( \frac{L + L_{Add}}{2} \right),$$

where  $\mu$  is the two-phase fluid dynamic viscosity. The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{\lambda \mu \dot{m}_{B2}}{2\rho D_H^2 A_{CS}} \left( \frac{L + L_{Add}}{2} \right).$$

For transitional flows, the pressure differential due to viscous friction is a smoothed blend between the values for laminar and turbulent pressure losses.

### Empirical Pressure Loss Formulation

When **Pressure loss model** is set to **Pressure loss coefficient**, the pressure losses due to viscous friction are calculated with an empirical pressure loss coefficient,  $\xi$ .

The pressure differential between port **A2** and internal node I2 is:

$$p_{A2} - p_{I2} = \frac{1}{2} \xi \frac{\dot{m}_{A2} |\dot{m}_{A2}|}{2\rho A_{CS}^2}.$$

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{1}{2} \xi \frac{\dot{m}_{B2} |\dot{m}_{B2}|}{2\rho A_{CS}^2}.$$

### Thermal Liquid Correlations

#### Heat Transfer Coefficient for Flows Inside One or More Tubes

When the thermal liquid **Flow geometry** is set to **Flow inside one or more tubes**, the Nusselt number is calculated according to the Gnielinski correlation in the same manner as two-phase subcooled liquid or superheated vapor. See "Heat Transfer Coefficient" on page 1-590 for more information.

#### Heat Transfer Coefficient for Flows Across a Tube Bank

When the thermal liquid **Flow geometry** is set to **Flow perpendicular to bank of circular tubes**, the Nusselt number is calculated based on the Hagen number,  $Hg$ , and depends on the **Tube bank grid arrangement** setting:

$$Nu = \begin{cases} 0.404 L q^{1/3} \left( \frac{Re+1}{Re+1000} \right)^{0.1}, & \text{Inline} \\ 0.404 L q^{1/3}, & \text{Staggered} \end{cases}$$

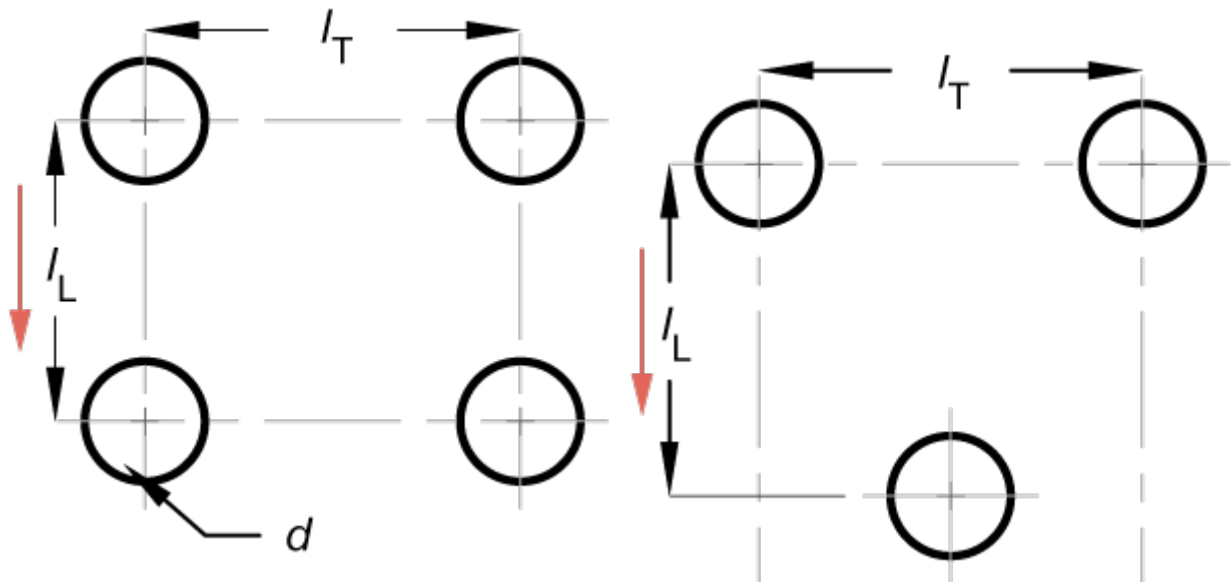
where:

$$Lq = \begin{cases} 1.18Pr \left( \frac{4l_T/\pi - D}{l_L} \right) \text{Hg}(\text{Re}), & \text{Inline} \\ 0.92Pr \left( \frac{4l_T/\pi - D}{l_D} \right) \text{Hg}(\text{Re}), & \text{Staggered with } l_L \geq D \\ 0.92Pr \left( \frac{4l_T l_L / \pi - D^2}{l_L l_D} \right) \text{Hg}(\text{Re}), & \text{Staggered with } l_L < D \end{cases}$$

- $D$  is the **Tube outer diameter**.
- $l_L$  is the **Longitudinal tube pitch (along flow direction)**, the distance between the tube centers along the flow direction. *Flow direction* refers to the thermal liquid flow.
- $l_T$  is the **Transverse tube pitch (perpendicular to flow direction)**, shown in the figure below. The transverse pitch is the distance between the centers of the two-phase fluid tubing in one row.
- $l_D$  is the diagonal tube spacing, calculated as  $l_D = \sqrt{\left(\frac{l_T}{2}\right)^2 + l_L^2}$ .

For more information on calculating the Hagen number, see [3].

The longitudinal and transverse pitch distances are the same for both grid bank arrangement types.



### Cross-Section of Two-Phase Fluid Tubing with Pitch Measurements

#### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** is set to Colburn equation or when **Flow geometry** is set to Generic, the Nusselt number is calculated by the empirical the Colburn equation:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c,$$

where  $a$ ,  $b$ , and  $c$  are the values defined in the **Coefficients [a, b, c] for a\*Re<sup>b</sup>\*Pr<sup>c</sup>** parameter.

### Pressure Loss for Flow Inside Tubes

When the thermal liquid **Flow geometry** is set to Flow inside one or more tubes, the pressure loss is calculated in the same manner as for two-phase flows, with the respective Darcy friction factor, density, mass flow rates, and pipe lengths of the thermal liquid side. See “Pressure Loss” on page 1-591 for more information.

### Pressure Loss for Flow Across Tube Banks

When the thermal liquid **Flow geometry** is set to Flow perpendicular to bank of circular tubes, the Hagen number is used to calculate the pressure loss due to viscous friction. The pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}),$$

where:

- $\mu_{\text{TL}}$  is the fluid dynamic viscosity.
- $N_R$  is the **Number of tube rows along flow direction**. This is the number of two-phase fluid tube rows along the thermal liquid flow direction.

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}).$$

### Empirical Pressure Loss Formulation

When the **Pressure loss model** is set to Euler number per tube row or when **Flow geometry** is set to Generic, the pressure loss due to viscous friction is calculated with a pressure loss coefficient, in terms of the Euler number,  $Eu$ :

$$Eu = \frac{\xi}{N_R},$$

where  $\xi$  is the empirical pressure loss coefficient.

The pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{1}{2} N_R Eu \frac{\dot{m}_{A1} |\dot{m}_{A1}|}{2\rho A_{CS}^2}.$$

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{1}{2} N_R Eu \frac{\dot{m}_{B1} |\dot{m}_{B1}|}{2\rho A_{CS}^2}.$$

## Conservation Equations

### Two-Phase Fluid

The total mass accumulation rate in the two-phase fluid is defined as:



$$\frac{dM_{2P}}{dt} = \dot{m}_{A2} + \dot{m}_{B2},$$

where:

- $M_{2P}$  is the total mass of the two-phase fluid.
- $\dot{m}_{A2}$  is the mass flow rate of the fluid at port **A2**.
- $\dot{m}_{B2}$  is the mass flow rate of the fluid at port **B2**.

The flow is positive when flowing into the block through the port.

The energy conservation equation relates the change in specific internal energy to the heat transfer by the fluid:

$$M_{2P} \frac{du_{2P}}{dt} + u_{2P}(\dot{m}_{A2} + \dot{m}_{B2}) = \phi_{A2} + \phi_{B2} - Q,$$

where:

- $u_{2P}$  is the two-phase fluid specific internal energy.
- $\phi_{A2}$  is the energy flow rate at port **A2**.
- $\phi_{B2}$  is the energy flow rate at port **B2**.
- $Q$  is heat transfer rate, which is positive when leaving the two-phase fluid volume.

### Thermal Liquid

The total mass accumulation rate in the thermal liquid is defined as:

$$\frac{dM_{TL}}{dt} = \dot{m}_{A1} + \dot{m}_{B1}.$$

The energy conservation equation is:

$$M_{TL} \frac{du_{TL}}{dt} + u_{TL}(\dot{m}_{A1} + \dot{m}_{B1}) = \phi_{A1} + \phi_{B1} + Q,$$

where:

- $\phi_{A1}$  is the energy flow rate at port **A1**.
- $\phi_{B1}$  is the energy flow rate at port **B1**.

The heat transferred to or from the thermal liquid,  $Q$ , is equal to the heat transferred from or to the two-phase fluid.

## Ports

### Conserving

#### A1 — Thermal liquid port

thermal liquid

Inlet or outlet port associated with the thermal liquid.

**B1 — Thermal liquid port**

thermal liquid

Inlet or outlet port associated with the thermal liquid.

**A2 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

**B2 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

**Output****Z — Two-phase fluid zone length fractions**

physical signal

Three-element vector of the zone length fractions in the two-phase fluid channel, returned as a physical signal. The vector takes the form [L, M, V], where L is the sub-cooled liquid, M is the liquid-vapor mixture, and V is the superheated vapor.

**Parameters****Configuration****Flow arrangement — Flow path alignment**

Cross flow (default) | Parallel flow | Counter flow

Flow path alignment between heat exchanger sides. The available flow arrangements are:

- `Parallel flow`. The flows run in the same direction.
- `Counter flow`. The flows run parallel to each other, in the opposite directions.
- `Cross flow`. The flows run perpendicular to each other.

**Cross flow arrangement — Thermal mixing condition in each of the flow channels**

Both fluids unmixed (default) | Both fluids mixed | Thermal Liquid 1 mixed &amp; Two-Phase Fluid 2 unmixed | Thermal Liquid 1 unmixed &amp; Two-Phase Fluid 2 mixed

Select whether each of the fluids can mix in its channel. Mixed flow means that the fluid is free to move in the transverse direction as it travels along the flow path. Unmixed flow means that the fluid is restricted to travel only along the flow path. For example, a side with fins is considered an unmixed flow.

**Dependencies**

To enable this parameter, set **Flow arrangement** to `Cross flow`.

**Thermal resistance through heat transfer surface — Wall thermal resistance**

0 K/kW (default) | positive scalar

Thermal resistance of the wall separating the two sides of the heat exchanger. The wall thermal resistance, wall fouling, and the fluid convective heat transfer coefficient influence the amount of heat transferred between the flows.

**Cross-sectional area at port A1 — Flow area at port A1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **A1**.

**Cross-sectional area at port B1 — Flow area at port B1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **B1**.

**Cross-sectional area at port A2 — Flow area at port A2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **A2**.

**Cross-sectional area at port B2 — Flow area at port B2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **B2**.

**Thermal Liquid 1**

**Flow geometry — Thermal liquid flow configuration**

Flow inside one or more tubes (default) | Flow perpendicular to bank of circular tubes | Generic

Thermal liquid flow path. The flow can run externally over a set of tubes or internal to a tube or set of tubes. You can also specify a generic parameterization based on empirical values.

**Number of tubes — Number of thermal liquid tubes**

25 (default) | positive scalar

Number of thermal liquid tubes. More tubes result in higher pressure losses due to viscous friction, but a larger amount of surface area for heat transfer.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Total length of each tube — Total length of each thermal liquid tube**

1 m (default) | positive scalar

Total length of each thermal liquid tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube cross section — Cross-sectional shape of a tube**

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of one tube. Set to Generic to specify an arbitrary cross-sectional geometry.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube inner diameter — Internal diameter of a single tube**

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Circular.

**Tube width — Internal width of a single tube**

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Tube height — Internal height of a single tube**

0.05 m (default) | positive scalar

Internal height of one tube. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Annulus inner diameter (heat transfer surface) — Smaller diameter of annular cross-section**

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Annular.

**Annulus outer diameter — Larger diameter of annular cross-section**

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Annular.

**Cross-sectional area per tube — Internal flow area in each tube**

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss — Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Perimeter of tube cross-section for heat transfer — Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Pressure loss model — Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Euler number per tube row | Pressure loss coefficient | Correlation for flow over tube bank

Method of pressure loss calculation due to viscous friction. Different models are available for different flow configurations. The settings are:

- Correlation for flow inside tubes. Use this setting to calculate the pressure loss with the Haaland correlation.
- Pressure loss coefficient. Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- Euler number per tube row. Use this setting to calculate the pressure loss based on an empirical Euler number.
- Correlation for flow over tube bank. Use this setting to calculate the pressure loss based on the Hagen number.

The pressure loss models available depend on the **Flow geometry** setting.

#### Dependencies

When **Flow geometry** is set to Flow inside one or more tubes, **Pressure loss model** can be set to either:

- Pressure loss coefficient.
- Correlation for flow inside tubes.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, **Pressure loss model** can be set to either:

- Correlation for flow over tube bank.
- Euler number per tube row.

When **Flow geometry** is set to Generic, the **Pressure loss model** parameter is disabled. Pressure loss is calculated empirically with the **Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$**  parameter.

#### Pressure loss coefficient, $\Delta p / (0.5 \cdot \rho \cdot v^2)$ — Empirical loss coefficient for all pressure losses in the channel

10 (default) | positive scalar

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. It is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2} \rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the thermal liquid density, and  $v$  is the flow velocity.

#### Dependencies

To enable this parameter, set either:

- **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Pressure loss coefficient.
- **Flow geometry** to Generic.

#### Aggregate equivalent length of local resistances — Combined length of all local resistances per tube

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlations for flow inside tubes.

**Internal surface absolute roughness – Mean surface roughness height**

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and either:

- **Pressure loss model**
- **Heat transfer coefficient model**

to Correlation for flow inside tubes.

**Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow**

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number limit**, the flow regime is transitional.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional between the laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter is also known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Correlation for flow inside tubes, **Tube cross section** to Generic, and **Pressure loss model** to Correlation for flow inside tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow over tube bank (default) | Colburn equation | Correlation for flow inside tubes

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- **Colburn equation.** Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$  of the Colburn equation.
- **Correlation for flow over tube bank.** Use this setting to calculate the heat transfer coefficient based on the tube bank correlation using the Hagen number.
- **Correlation for flow inside tubes.** Use this setting to calculate the heat transfer coefficient for pipe flows with the Gnielinski correlation.

#### Dependencies

To enable this parameter, set **Flow geometry** to either:

- Flow perpendicular to bank of circular tubes.
- Flow inside one or more tubes.

#### Coefficients [a, b, c] for $a \cdot \text{Re}^b \cdot \text{Pr}^c$ — Colburn equation coefficients

[0.023, 0.8, 0.33] (default) | three-element vector

Three-element vector containing the empirical coefficients of the Colburn equation. The Colburn equation is a formulation for calculating the Nusselt Number. The general form of the Colburn equation is:

$$\text{Nu} = a \text{Re}^b \text{Pr}^c.$$

When the **Heat transfer coefficient model** is set to Colburn equation and **Flow geometry** is set to Flow inside one or more tubes, or **Flow geometry** is set to Generic, the default Colburn equation is:

$$\text{Nu} = 0.023 \text{Re}^{0.8} \text{Pr}^{1/3}.$$

When the **Heat transfer coefficient model** is set to Colburn equation and **Flow geometry** is set to Flow perpendicular to bank of circular tubes, the default Colburn equation is:

$$\text{Nu} = 0.27 \text{Re}^{0.63} \text{Pr}^{0.36}.$$

#### Dependencies

To enable this parameter, set:

##### 1 **Flow geometry** to either:

- Flow inside one or more tubes
- Flow perpendicular to bank of circular tubes

and **Heat transfer coefficient model** to Colburn equation.

##### 2 **Flow geometry** to Generic.

#### Laminar flow Nusselt number — Ratio of convective to conductive heat transfer in the laminar flow regime

3.66 (default) | positive scalar



Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes, **Tube cross-section** to Generic, and **Heat transfer parameterization** to Correlation for flow inside tubes.

#### Tube bank grid arrangement — Geometrical placement of tube rows in the bank

Inline (default) | Staggered

Alignment of tubes in a tube bank. Rows are either in line with their neighbors, or staggered.

- **Inline:** All tube rows are located directly behind each other.
- **Staggered:** Tubes of the one tube row are located at the gap between tubes of the previous tube row.

Tube alignment influences the Nusselt number and the heat transfer rate.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

#### Number of tube rows along flow direction — Number of two-phase fluid tube rows in the tube bank

5 (default) | positive scalar

Number of two-phase fluid tube rows in a tube bank. The rows are aligned with the direction of thermal liquid flow.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

#### Number of tube segments in each tube row — Number of two-phase fluid tubes in each row of the tube bank

5 (default) | positive scalar

Number of two-phase fluid tubes in each row of a tube bank. This measurement is perpendicular to the thermal liquid flow.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

#### Length of each tube segment in a tube row — Length of each two-phase fluid tube

1 m (default) | positive scalar

Length of each tube that spans a tube row. All tubes in a tube bank are the same length.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Tube outer diameter — External diameter of a single two-phase fluid tube**

0.05 m (default) | positive scalar

Outer diameter of a two-phase fluid tube. The cross-section is uniform along a tube and so the diameter is constant throughout. This value influences the losses in the flow across a tube bank due to viscous friction.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Longitudinal tube pitch (along flow direction) — Center-to-center distance between two-phase fluid tube rows**

0.15 m (default) | positive scalar

Distance between tube centers of the two-phase fluid tubes, aligned with the direction of flow of the thermal liquid.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Transverse tube pitch (perpendicular to flow direction) — Center-to-center distance between two-phase fluid tubes in a row**

0.15 m (default) | positive scalar

Distance between the tube centers in a row of two-phase fluid tubes. This measurement is perpendicular to the thermal liquid flow direction. See “Heat Transfer Coefficient for Flows Across a Tube Bank” on page 1-592 for more information.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Euler number per tube row,  $\Delta p / (N \cdot 0.5 \cdot \rho \cdot v^2)$  — Euler number for each row of the tube bank**

10 (default) | positive scalar

Empirical coefficient for pressure drop across one tube row. The Euler number is the ratio between pressure drop and fluid momentum:

$$Eu = \frac{\Delta p}{N \frac{1}{2} \rho v^2},$$

where  $N$  is the **Number of tube rows along flow direction**,  $\Delta p$  is the pressure drop,  $\rho$  is the thermal liquid mixture density, and  $v$  is the flow velocity.

Each tube row is located in a plane perpendicular to the thermal liquid flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes and **Pressure loss model** to Euler number per tube row.

**Minimum free-flow area — Smallest total flow area between inlet and outlet**

0.01 m<sup>2</sup> (default) | positive scalar

Smallest total flow area between inlet and outlet. If the channel is a collection of ducts, tubes, slots, or grooves, the minimum free-flow area is the sum of the smallest areas.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Heat transfer surface area without fins — Total area of the heat transfer surface excluding fins**

2 m<sup>2</sup> (default) | positive scalar

Total area of the heat transfer surface, excluding fins.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Thermal liquid volume inside heat exchanger — Total volume of thermal liquid in the heat exchanger**

0.05 m<sup>3</sup> (default) | positive scalar

Total volume of thermal liquid in the heat exchanger.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Fouling factor — Additional thermal resistance due to fouling deposits**

0.1 m<sup>2</sup>\*K/kW (default) | positive scalar

Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time. However, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area — Total heat transfer surface area of all fins**

0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency — Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial thermal liquid pressure — Moist air pressure at the start of simulation**

0.101325 MPa (default) | positive scalar

Thermal liquid pressure at the start of the simulation.

**Initial thermal liquid temperature — Temperature at the start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the thermal liquid channel at the start of the simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Two-Phase Fluid 2****Number of tubes — Number of two-phase fluid tubes**

25 (default) | positive scalar

Number of two-phase fluid tubes.

**Total length of each tube — Total length of each two-phase fluid tube**

1 m (default) | positive scalar

Total length of each two-phase fluid tube.

**Tube cross section — Cross-sectional shape of a tube**

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of a tube. Use `Generic` to specify an arbitrary cross-sectional geometry.

**Tube inner diameter — Internal diameter of a single tube**

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to `Circular`.

**Tube width — Internal width of a single tube**

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to `Rectangular`.

**Tube height — Internal height of a single tube**

0.05 m (default) | positive scalar

Internal height of one tube. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Rectangular.

**Annulus inner diameter (heat transfer surface) – Smaller diameter of annular cross-section**

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Annular.

**Annulus outer diameter – Larger diameter of annular cross-section**

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Annular.

**Cross-sectional area per tube – Internal area normal to flow in a single tube**

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss – Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Perimeter of tube cross-section for heat transfer – Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Tube cross-section** to Generic.

**Pressure loss model – Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Pressure loss coefficient

Method of pressure loss calculation due to viscous friction. The settings are:

- **Pressure loss coefficient.** Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- **Correlation for flow inside tubes.** Use this setting to calculate the pressure loss based on the pipe flow correlation.

**Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$  – Empirical loss coefficient for all pressure losses in the channel**

10 (default)

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. It is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2} \rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the two-phase fluid density, and  $v$  is the flow velocity.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Pressure loss coefficient.

**Aggregate equivalent length of local resistances – Combined length of all local resistances per tube**

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Correlation for flow inside tubes.

**Internal surface absolute roughness – Mean surface roughness height**

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.

**Dependencies**

To enable this parameter, set either:

- **Pressure loss model**
- **Heat transfer coefficient model**

to Correlation for flow inside tubes.

**Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow**

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number**, the flow regime is transitional.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Correlations for tubes.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Correlations for tubes.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter may also be known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Pressure loss model** to Correlations for tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow inside tubes (default) | Colburn equation

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- **Colburn equation.** Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$ . In the liquid and vapor zones, the heat transfer coefficient is based on the Colburn equation. In the liquid-vapor mixture zone, the heat transfer coefficient is based on the Cavallini-Zecchin equation.
- **Correlation for flow inside tubes.** Use this setting to calculate the heat transfer coefficient for pipe flows. In the liquid and vapor zones, the heat transfer coefficient is calculated with the Gnielinski correlation. In the liquid-vapor mixture zone, the heat transfer coefficient is calculated with the Cavallini-Zecchin equation.

**Coefficients [a, b, c] for  $a \cdot Re^b \cdot Pr^c$  in liquid zone – Colburn equation coefficients in liquid zone**

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector containing the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which is calculated by the Colburn equation per zone. The general form of the Colburn equation is:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c.$$

#### Dependencies

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

#### Coefficients [a, b, c] for $a\text{Re}^b\text{Pr}^c$ in mixture zone — Cavallini-Zecchin equation coefficients in mixture zone

[.05, .8, .33] (default) | three-element vector of positive scalars

Three-element vector containing the empirical coefficients of the Cavallini-Zecchin equation. Each fluid zone has a distinct Nusselt number, which is calculated in the mixture zone by the Cavallini-Zecchin equation:

$$\text{Nu} = \frac{a\text{Re}_{\text{SL}}^b\text{Pr}_{\text{SL}}^c \left\{ \left[ \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) x_{\text{Out}} + 1 \right]^{1+b} - \left[ \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) x_{\text{In}} + 1 \right]^{1+b} \right\}}{(1+b) \left( \sqrt{\frac{\rho_{\text{SL}}}{\rho_{\text{SV}}}} - 1 \right) (x_{\text{Out}} - x_{\text{In}})}.$$

#### Dependencies

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

#### Coefficients [a, b, c] for $a\text{Re}^b\text{Pr}^c$ in vapor zone — Colburn equation coefficients in vapor zone

[.023, .8, .33] (default) | three-element vector of positive scalars

Three-element vector containing the empirical coefficients of the Colburn equation. Each fluid zone has a distinct Nusselt number, which is calculated by the Colburn equation per zone. The general form of the Colburn equation is:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c.$$

#### Dependencies

To enable this parameter, set **Heat transfer coefficient model** to Colburn equation.

#### Laminar flow Nusselt number — Ratio of convective to conductive heat transfer in the laminar flow regime

3.66 (default) | positive scalar

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

#### Dependencies

To enable this parameter, set **Heat transfer coefficient model** to Correlation for flow inside tubes.

#### Fouling factor — Additional thermal resistance due to fouling deposits

0.1 m<sup>2</sup>\*K/kW (default) | positive scalar



Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time, however, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area — Total heat transfer surface area of fins**

0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency — Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial fluid energy specification — Initial state of the two-phase fluid**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Quantity used to describe the initial state of the fluid.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- **Temperature** — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- **Vapor quality** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Vapor void fraction** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

**Initial two-phase fluid pressure — Fluid pressure at the start of simulation**

0.101325 MPa (default) | positive scalar

Fluid pressure at the start of the simulation.

**Initial two-phase fluid temperature — Temperature at the start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A

vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Temperature.

**Initial two-phase fluid vapor quality – Vapor mass fraction at the start of simulation**

0.5 (default) | positive scalar in the range [0,1] | two-element vector

Vapor mass fraction in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial vapor quality in the channel. A vector value represents the initial vapor quality at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

**Initial two-phase fluid vapor void fraction – Vapor volume fraction at the start of simulation**

0.5 (default) | positive scalar in the range [0,1] | two-element vector

Vapor volume fraction in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial void fraction in the channel. A vector value represents the initial void fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

**Initial two-phase fluid specific enthalpy – Enthalpy per unit mass at the start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Enthalpy per unit mass in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific enthalpy in the channel. A vector value represents the initial specific enthalpy at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

**Initial two-phase fluid specific internal energy – Internal energy per unit mass at the start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Internal energy per unit mass in the two-phase fluid channel at the start of simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific

internal energy in the channel. A vector value represents the initial specific internal energy at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

## Version History

Introduced in R2020b

### References

- [1] *2013 ASHRAE Handbook - Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013.
- [2] Çengel, Yunus A. *Heat and Mass Transfer: A Practical Approach*. 3rd ed, McGraw-Hill, 2007.
- [3] Shah, R. K., and Dušan P. Sekulić. *Fundamentals of Heat Exchanger Design*. John Wiley & Sons, 2003.
- [4] White, Frank M. *Fluid Mechanics*. 6th ed, McGraw-Hill, 2009.

### Extended Capabilities

#### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Thermostatic Expansion Valve (2P) | Condenser Evaporator (2P-MA) | Heat Exchanger (TL-MA) | E-NTU Heat Transfer | Heat Exchanger (G-TL) | Heat Exchanger (TL-TL)

## Constant Head Tank

Hydraulic reservoir where pressurization and fluid level remain constant regardless of volume change



### Library

Low-Pressure Blocks

### Description

The Constant Head Tank block represents a pressurized hydraulic reservoir, in which fluid is stored under a specified pressure. The size of the tank is assumed to be large enough to neglect the pressurization and fluid level change due to fluid volume. The block accounts for the fluid level elevation with respect to the tank bottom, as well as for pressure loss in the connecting pipe that can be caused by a filter, fittings, or some other local resistance. The loss is specified with the pressure loss coefficient. The block computes the volume of fluid in the tank and exports it outside through the physical signal port V.

The fluid volume value does not affect the results of simulation. It is introduced merely for information purposes. It is possible for the fluid volume to become negative during simulation, which signals that the fluid volume is not enough for the proper operation of the system. By viewing the results of the simulation, you can determine the extent of the fluid shortage.

For reasons of computational robustness, the pressure loss in the connecting pipe is computed with the equations similar to that used in the Fixed Orifice block:

$$q = \sqrt{\frac{1}{K}} \cdot A_p \sqrt{\frac{2}{\rho}} \cdot \frac{p_{loss}}{(p_{loss}^2 + p_{cr}^2)^{1/4}}$$

$$p_{cr} = K \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{d} \right)^2$$

The Critical Reynolds number is set to 15.

The pressure at the tank inlet is computed with the following equations:

$$p = p_{elev} - p_{loss} + p_{pr}$$

$$p_{elev} = \rho \cdot g \cdot H$$

$$A_p = \frac{\pi \cdot d^2}{4}$$

where

$p$	Pressure at the tank inlet
$p_{elev}$	Pressure due to fluid level
$p_{loss}$	Pressure loss in the connecting pipe
$p_{pr}$	Pressurization
$\rho$	Fluid density
$g$	Acceleration of gravity
$H$	Fluid level with respect to the bottom of the tank
$K$	Pressure loss coefficient
$A_p$	Connecting pipe area
$d$	Connecting pipe diameter
$q$	Flow rate
$p_{cr}$	Minimum pressure for turbulent flow

Connection T is a hydraulic conserving port associated with the tank inlet. Connection V is a physical signal port. The flow rate is considered positive if it flows into the tank.

## Parameters

### Pressurization

Gage pressure acting on the surface of the fluid in the tank. It can be created by a gas cushion, membrane, bladder, or piston, as in bootstrap reservoirs. This parameter must be greater than or equal to zero. The default value is 0, which corresponds to a tank connected to atmosphere.

### Fluid level

The fluid level with respect to the tank bottom. This parameter must be greater than zero. The default value is 1 m.

### Initial fluid volume

The initial volume of fluid in the tank. This parameter must be greater than zero. The default value is  $0.2 \text{ m}^3$ .

### Inlet pipeline diameter

The diameter of the connecting pipe. This parameter must be greater than zero. The default value is  $0.02 \text{ m}$ .

### Pipeline pressure loss coefficient

The value of the pressure loss coefficient, to account for pressure loss in the connecting pipe. This parameter must be greater than zero. The default value is 1.2.

## Ports

The block has the following ports:

T

Hydraulic conserving port associated with the tank inlet.

V

Physical signal port that outputs the volume of fluid in the tank.

## **Version History**

**Introduced in R2009a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Reservoir | Tank

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Counterbalance Valve

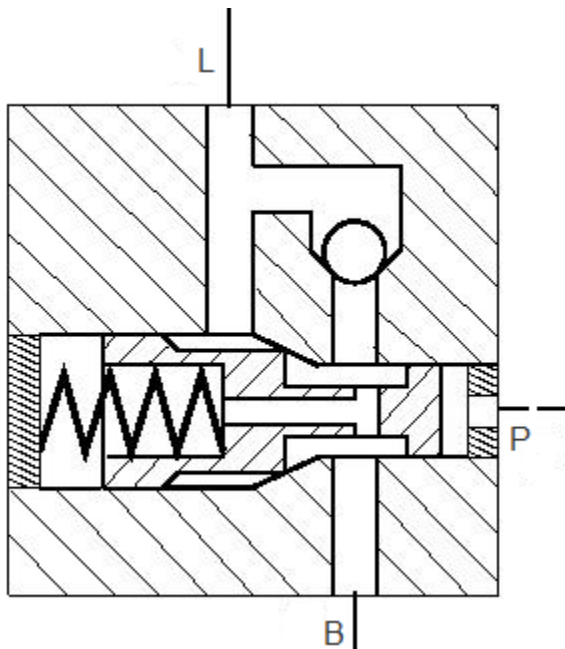
Hydraulic counterbalance valve

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Flow Control Valves



## Description

Counterbalance valves are used in hydraulic systems working with an overriding (run-away) or suspended load. They are designed to create backpressure at the return line of the actuator to prevent losing control over the load. The following illustration shows a counterbalance valve schematic.



If a directional valve (not shown in the picture) is shifted into position that lowers the load, then the fluid from the rod chamber of the cylinder can exit only if pressure at port P (pilot pressure) and port L (load pressure) create enough force to overcome the spring force and open the valve. In statics, the valve is described with the equation

$$F_0 + c \cdot x = p_{pilot} \cdot A_{pilot} + p_{load} \cdot A_{load} - p_{back} \cdot A_{back} \quad (1-5)$$

where

$F_0$	Spring setting
-------	----------------

$c$	Spring rate
$x$	Valve opening
$p_{pilot}$	Pilot pressure (pressure at port P)
$p_{load}$	Load pressure (pressure at port L)
$p_{back}$	Backpressure (pressure at return port B)
$A_{pilot}$	Valve effective area at pilot port P
$A_{load}$	Valve effective area at load port L
$A_{back}$	Valve effective area at return port B

Counterbalance valve, classified by type, is an internally-externally piloted valve because both the pilot pressure and the load pressure tend to open the valve. After minor rearrangements, Equation 1 takes the form

$$p_{set} + c_p \cdot x = p_{pilot} \cdot k_{pilot} + p_{load} - p_{back} \cdot k_{back} \quad (1-6)$$

$$p_{set} = F_0/A_{load}$$

$$c_p = c/A_{load}$$

$$k_{pilot} = A_{pilot}/A_{load}$$

$$k_{back} = A_{back}/A_{load}$$

where

$p_{set}$	Valve pressure setting
$c_p$	Spring pressure stiffness (Pa/m)
$x$	Valve opening
$k_{pilot}$	Pilot ratio
$k_{back}$	Backpressure ratio

The valve displacement is determined from Equation 2:

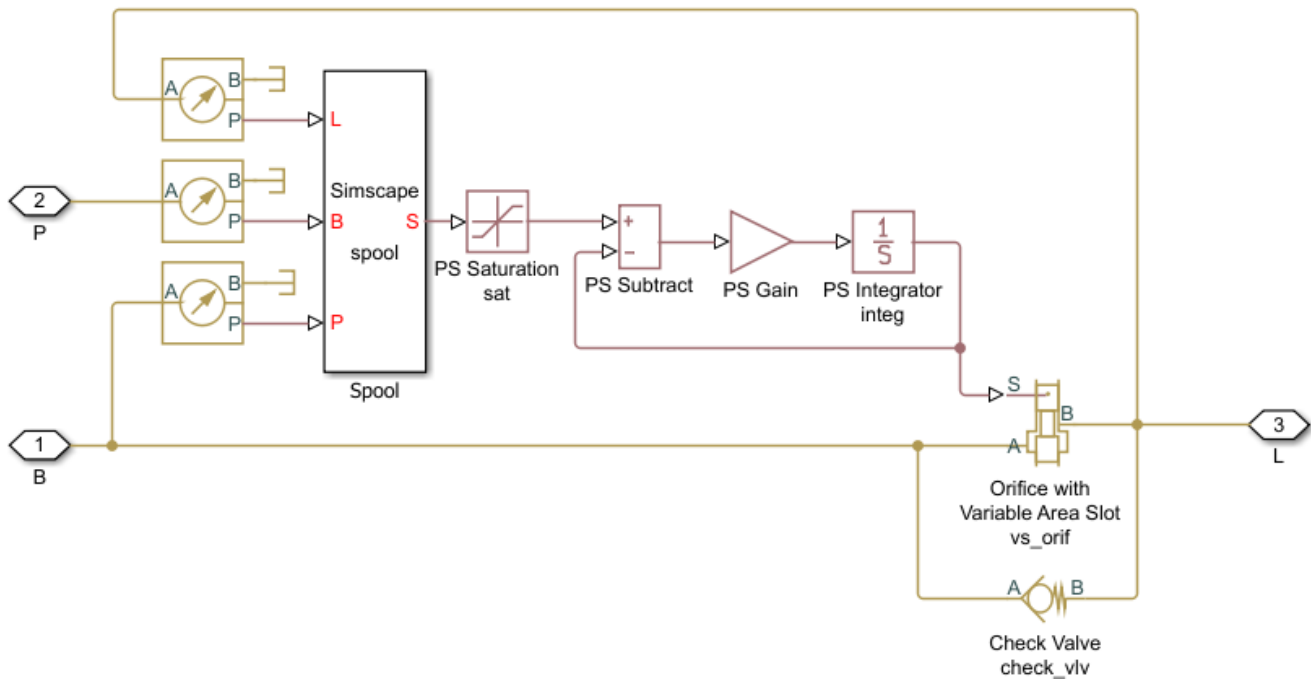
$$x = \frac{p_{pilot} \cdot k_{pilot} + p_{load} - p_{back} \cdot k_{back} - p_{set}}{c_p} \quad (1-7)$$

$$0 \leq x \leq x_{max}$$

where  $x_{max}$  is the maximum valve displacement.

The Counterbalance Valve block can be represented as the following structural model.





The pressure sensors measure pressure at respective ports and convey their values to the Fcn block, which, together with the PS Saturation block, performs calculations in accordance with Equation 3. The valve displacement is passed through the first order lag block, built of the PS Subtract, PS Gain, and PS Integrator blocks, to account for valve dynamics. The gain of the PS Gain block is set to  $1/T$ , where  $T$  is the time constant. The Variable Orifice and Check Valve blocks simulate the counterbalance valve orifice and check valve. In the actual Counterbalance Valve block model, the operations performed by the sensors and the Fcn block are executed in the block equation section.

The Counterbalance Valve block is essentially a data-sheet-based model. Depending on data listed in the manufacturer's catalogs or data sheets for your particular valve, you can choose one of the following model parameterization options:

- By maximum area and opening — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.
- By area vs. opening table — Use this option if the catalog or data sheet provides a table of the orifice passage area based on the control member displacement.

In the latter case, the PS Saturation block in the structural model is replaced with the PS Lookup Table (1D) block, and you can choose from three interpolation and two extrapolation methods.

Connections L and B are hydraulic conserving ports associated with the load and backpressure ports of the valve. The hydraulic conserving port P is associated with the pilot port. The block positive direction is from port L to port B. Positive pressure at port P opens the valve.

### Assumptions and Limitations

- Valve dynamics are approximated by introducing the first order lag between the pressure sensors and the variable orifice control member displacement.

- Inertia, friction, or hydraulic forces acting on the valve control member are not taken into account.

## Ports

### Conserving

#### **P – Pilot port**

isothermal liquid

Hydraulic conserving port associated with the valve pilot port.

#### **L – Load port**

isothermal liquid

Hydraulic conserving port associated with the valve load port.

#### **B – Backpressure port**

isothermal liquid

Hydraulic conserving port associated with the valve backpressure port.

## Parameters

### Basic parameters

#### **Valve pressure setting – Cracking pressure at port L**

50e5 Pa (default) | positive scalar

The parameter specifies the pressure at port **L** necessary to start opening the valve. The setting is controlled with the valve spring.

#### **Valve spring stiffness – Spring stiffness at port L**

1e8 Pa/m (default) | positive scalar

The valve spring pressure stiffness  $c_p$ .

#### **Pilot ratio – Ratio of pilot to load chamber area**

3 (default) | positive scalar

The ratio between the effective areas of the control member face in the pilot chamber and in the load chamber. This is one of the fundamental valve characteristics in a catalog or data sheet. The default value is 3.

#### **Backpressure ratio – Ratio of back pressure port to load port area**

4 (default) | positive scalar

The ratio between the effective area of the control member, onto which the backpressure acts, and the load chamber valve area. There is a wide variety of counterbalance valves with compensated or partially-compensated backpressure. The parameter can take zero value if the valve is completely compensated.

#### **Time constant – Valve opening time constant**

0.06 s (default) | positive scalar

The valve dynamics are approximated with the first order lag. This parameter is the time constant of the lag.

#### **Leakage area — Open area of fully closed valve**

1e-9 m<sup>2</sup> (default) | positive scalar

The total area of possible leaks in the completely closed orifice and check valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the orifice or check valve is completely closed. The parameter value must be greater than 0.

#### **Variable orifice**

##### **Variable orifice parameterization — Method of variation**

By maximum area and opening (default) | By area vs. opening table

Select one of the following methods for specifying the orifice:

- **By maximum area and opening** — Provide values for the maximum orifice area and the maximum orifice opening. The passage area is linearly dependent on the control member displacement, that is, the orifice is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement.
- **By area vs. opening table** — Provide tabulated data of orifice openings and corresponding orifice areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

##### **Orifice maximum area — Maximum opened area**

8e-5 m<sup>2</sup> (default) | positive scalar

Specify the area of a fully opened orifice. The parameter value must be greater than zero. This parameter is used if **Variable orifice parameterization** is set to By maximum area and opening.

##### **Orifice maximum opening — Maximum opened length**

5e-3 m (default) | positive scalar

Specify the maximum displacement of the control member. The parameter value must be greater than zero. This parameter is used if **Variable orifice parameterization** is set to By maximum area and opening.

##### **Tabulated orifice opening — Control member length tabulated data**

[-.002, 0, .005, .015] (default) | numerical array

Specify the vector of input values for orifice openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are [-2e-3, 0, 5e-3, 15e-3]. This parameter is used if **Variable orifice parameterization** is set to By area vs. opening table. **Tabulated orifice openings** values will be used together with **Tabulated orifice area** values for one-dimensional table lookup.

##### **Tabulated orifice area — Open area tabulated data**

[1e-09, 4e-09, 1e-05, 1.02e-05] (default) | numerical array

Specify the vector of orifice areas as a one-dimensional array. The vector must be of the same size as the orifice openings vector. All the values must be positive. The default values, in m<sup>2</sup>, are

[1e-12, 4e-12, 1.e-5, 1.02e-5]. This parameter is used if **Variable orifice parameterization** is set to **By area vs. opening table**.

### Interpolation method — Tabular interpolation

Linear (default) | Smooth

This parameter is used if **Variable orifice parameterization** is set to **By area vs. opening table**. Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

### Extrapolation method — Tabular extrapolation

Linear (default) | Nearest

This parameter is used if **Variable orifice parameterization** is set to **By area vs. opening table**. Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page.

### Orifice flow discharge coefficient — Orifice discharge coefficient

0.7 (default) | positive scalar

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets.

### Orifice laminar transition specification — Method for identifying fluid regime transition

Pressure ratio (default) | Reynolds number

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Orifice laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Orifice critical Reynolds number** parameter.

### Orifice laminar flow pressure ratio — Pressure ratio at fluid regime transition

0.999 (default) | positive scalar

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Orifice laminar transition specification** parameter is set to Pressure ratio.

#### **Orifice critical Reynolds number — Upper limit to laminar flow**

12 (default) | positive scalar

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Orifice laminar transition specification** parameter is set to Reynolds number.

#### **Check valve**

##### **Check valve maximum passage area — Maximum valve open area**

$1e-4 \text{ m}^2$  (default) | positive scalar

Valve passage maximum cross-sectional area.

##### **Check valve cracking pressure — Threshold for valve opening**

$0.3e5 \text{ Pa}$  (default) | positive scalar

Pressure level at which the orifice of the valve starts to open.

##### **Check valve maximum opening pressure — Valve maximum pressure**

$1.2e5 \text{ Pa}$  (default) | positive scalar

Pressure differential across the valve needed to fully open the valve. Its value must be higher than the cracking pressure. The default value is  $1.2e5 \text{ Pa}$ .

##### **Check valve flow discharge coefficient — Discharge coefficient**

0.7 (default)

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

##### **Check valve laminar transition specification — Method for identifying fluid regime transition**

Pressure ratio (default) | Reynolds number

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Check valve laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Check valve critical Reynolds number** parameter.

##### **Check valve laminar flow pressure ratio — Pressure ratio at fluid regime transition**

0.999 (default) | positive scalar

Pressure ratio at which the flow transitions between laminar and turbulent regimes. This parameter is visible only if the **Check valve laminar transition specification** parameter is set to Pressure ratio.

**Check valve critical Reynolds number — Upper limit to laminar flow through check valve**

12 (default) | positive scalar

The maximum Reynolds number for laminar flow. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Check valve laminar transition specification** parameter is set to Reynolds number.

## Version History

Introduced in R2012b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Counterbalance Valve (IL) | Check Valve | Variable Orifice

## Topics

“Hydraulic Actuator with Counterbalance Valve”

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Counterbalance Valve (IL)

High-pressure regulation valve in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Pressure Control Valves

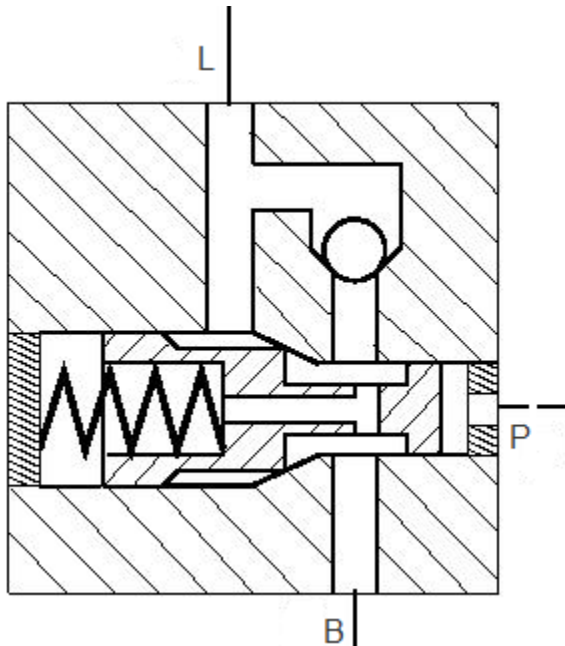


### Description

The Counterbalance Valve (IL) block represents a counterbalance pressure control valve in an isothermal liquid network. A counterbalance valve is common in applications where high-pressure events are common or when a task requires high-pressure controlled manipulation at production speeds. This includes tasks such as overloading hydraulics or lowering suspended loads. The valve functions under the force balance between a spring, the back pressure at port **B**, and the load pressure at port **L**. The valve responds to changes in the pilot line pressure. When the pilot pressure exceeds the back pressure, the valve begins to open.

There is no flow between ports **B** and **P** or ports **L** and **P**.

This figure shows a typical counterbalance valve cutaway.



### Valve Opening

The block balances the forces of the counterbalance valve, such that

$$p_{pilot}A_{pilot} + p_{load}A_{load} = p_{back}A_{back} + F_{set} + k_{spring}x_{spool}$$

where:

- $p_{pilot}$  is the pressure at port **P**.
- $p_{load}$  is the pressure at port **L**.
- $p_{back}$  is the pressure at port **B**.
- $F_{set}$  is the accumulated force due to the spring.
- $k_{spring}$  is the spring constant.
- $x_{spool}$  is the linear position of the relief stage spool body. This position is relative to the unpressurized installed position.

The block sets the pressure-acting areas  $A_{pilot}$ ,  $A_{load}$ , and  $A_{back}$  according to the **Pilot ratio** parameter,  $R_{pilot}$ , such that

$$R_{pilot} = \frac{A_{pilot}}{A_{load}},$$

and the **Back pressure ratio** parameter,  $R_{back}$ , such that

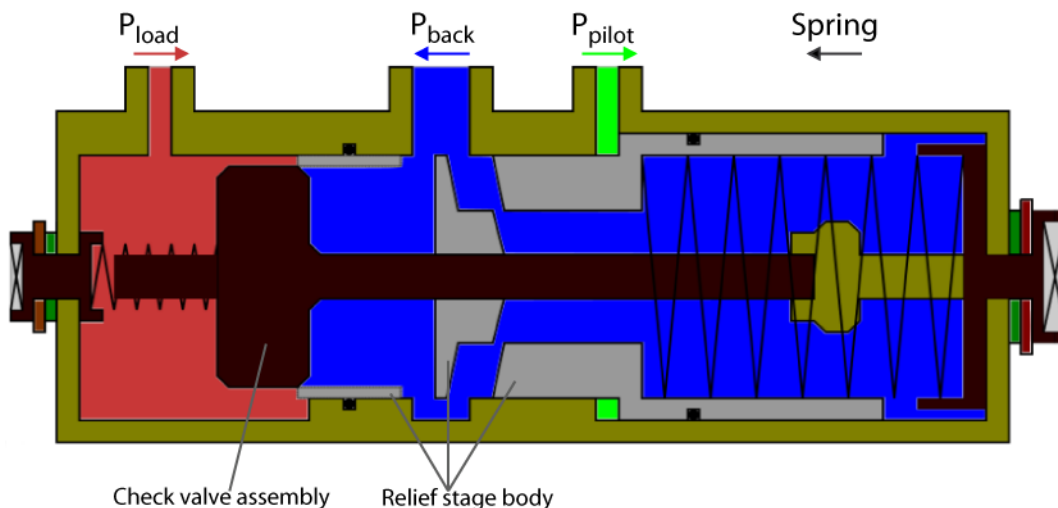
$$R_{back} = \frac{A_{back}}{A_{load}}.$$

A ratio of 4:1 or 3:1 is typical for counterbalance valves.

The preset force,  $F_{spring}$ , represents the combined spring preloading and spring force at port **B**. This force is a function of  $p_{set}$ , the **Set pressure differential** parameter, such that

$$F_{set} = p_{set}A_{load}.$$

This figure shows the schematic from the “Counterbalance Valve With Test Harness” example where the pressure ports control the valve by acting on surfaces with differential area. The arrows show the direction of force due to pressure or spring force acting on the relief stage body. The gray sections represent a single, solid body that moves to the right when the relief stage opens. The check valve travels to the left when it opens.





## Opening Parameterization

The block accepts linear or tabulated parameterizations. The check valve portion of the block operates identically to the Check Valve (IL) block.

### Linear Parameterization

When you set **Opening parameterization** to Linear - Area vs. pressure, the block calculates the valve opening area, such that

$$A_{valve} = \hat{p}(A_{max} - A_{leak}) + A_{leak}.$$

The block calculates the normalized control pressure,  $\hat{p}$ , as

$$\hat{p} = \frac{(p_{load} + p_{pilot}R_{pilot} - p_{back}R_{back}) - p_{set}}{(p_{max} - p_{set})},$$

where  $p_{max}$  is the **Maximum opening pressure differential** parameter.

The normalized check valve pressure is

$$\hat{p} = \frac{p_{control} - p_{cracking}}{p_{max} - p_{cracking}},$$

where:

- $p_{cracking}$  is the **Cracking pressure differential** parameter.
- $p_{max}$  is the check valve **Maximum opening pressure differential** parameter.

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{cracking}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

### Tabulated Area Parameterization

When you set **Opening parameterization** to Tabulated data - Area vs. pressure, the block uses the same equations as for the linear parameterization but with tabulated data. The tabulated data represents area with respect to a given control pressure, where  $P_{control} = p_{load} + p_{pilot}R_{pilot} - p_{back}R_{back}$ . The first element of the **Pressure differential vector** parameter is the set pressure, which is the control pressure when the relief stage begins to open. The last element defines the control pressure when the valve is fully open.

### Tabulated Flow Rate Parameterization

When you set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure, the volumetric flow rate equations refer to these quantities:

- $\bar{\rho}_{valve}$  is the simulated average density of relief stage flow.
- $K$  is the flow coefficient through the relief stage.
- $\Delta p_{valve}$  is the pressure drop across the relief stage during flow.
- $\Delta p_{crit}$  is the critical pressure drop across the relief stage during flow.
- $p_{control}$  is the simulated control pressure.

- $p_{control,TLU,Ref}$  is an internally derived lookup table of changing control pressures.
- $p_{set}$  is the set pressure differential.
- $Re_{crit}$  is the **Critical Reynolds number** parameter.
- $C_d$  is the **Discharge coefficient** parameter.
- $\nu$  is the kinematic viscosity.
- $K_{TLU,Ref}$  is an internally derived lookup table of changing flow coefficients as a function of valve area.
- $\dot{V}_{TLU,Ref}$  is the reference volumetric flow rate vector.
- $p_{pilot,Ref}$ ,  $p_{back,Ref}$ ,  $p_{load,Ref}$  are the pilot pressure, back pressure, and load pressure for the user-provided **Reference volumetric flow rate vector** parameter, respectively.

The block calculates the mass flow rate for the relief stage such that

$$\dot{m}_{valve} = \bar{\rho}_{valve} K \frac{\Delta p_{valve}}{(\Delta p_{valve}^2 + \Delta p_{crit}^2)^{1/4}},$$

where:

$$\begin{aligned} \Delta p_{valve} &= p_{load} - p_{back} \\ \Delta p_{crit} &= \frac{\pi \sqrt{2} \bar{\rho}_{valve}}{8 C_d} (Re_{crit} \nu) \end{aligned}$$

$$K = \text{tablelookup}(p_{control,TLU,Ref}, K_{TLU,Ref}, p_{control}, \text{interpolation} = \text{linear}, \text{extrapolation} = \text{nearest})$$

Liquid flows from the load port to the back port. The block extrapolates  $K$  to the nearest point after it calculates  $K_{TLU,Ref}$  as

$$K_{TLU,Ref} = \frac{\dot{V}_{TLU,Ref}}{\sqrt{\Delta p_{valve,TLU,ref}}},$$

where  $\Delta p_{valve,TLU,ref} = p_{load,Ref} - p_{back,Ref}$ . The block calculates the control pressure as

$$p_{control} = R_{pilot} p_{pilot} + p_{load} - R_{back} p_{back}$$

and the reference control vector as

$$p_{control,TLU,Ref} = R_{pilot} p_{pilot,Ref} + p_{load,Ref} - R_{back} p_{back,Ref} + p_{offset}$$

where:

$$p_{pilot,Ref} = 1 \text{ atm}$$

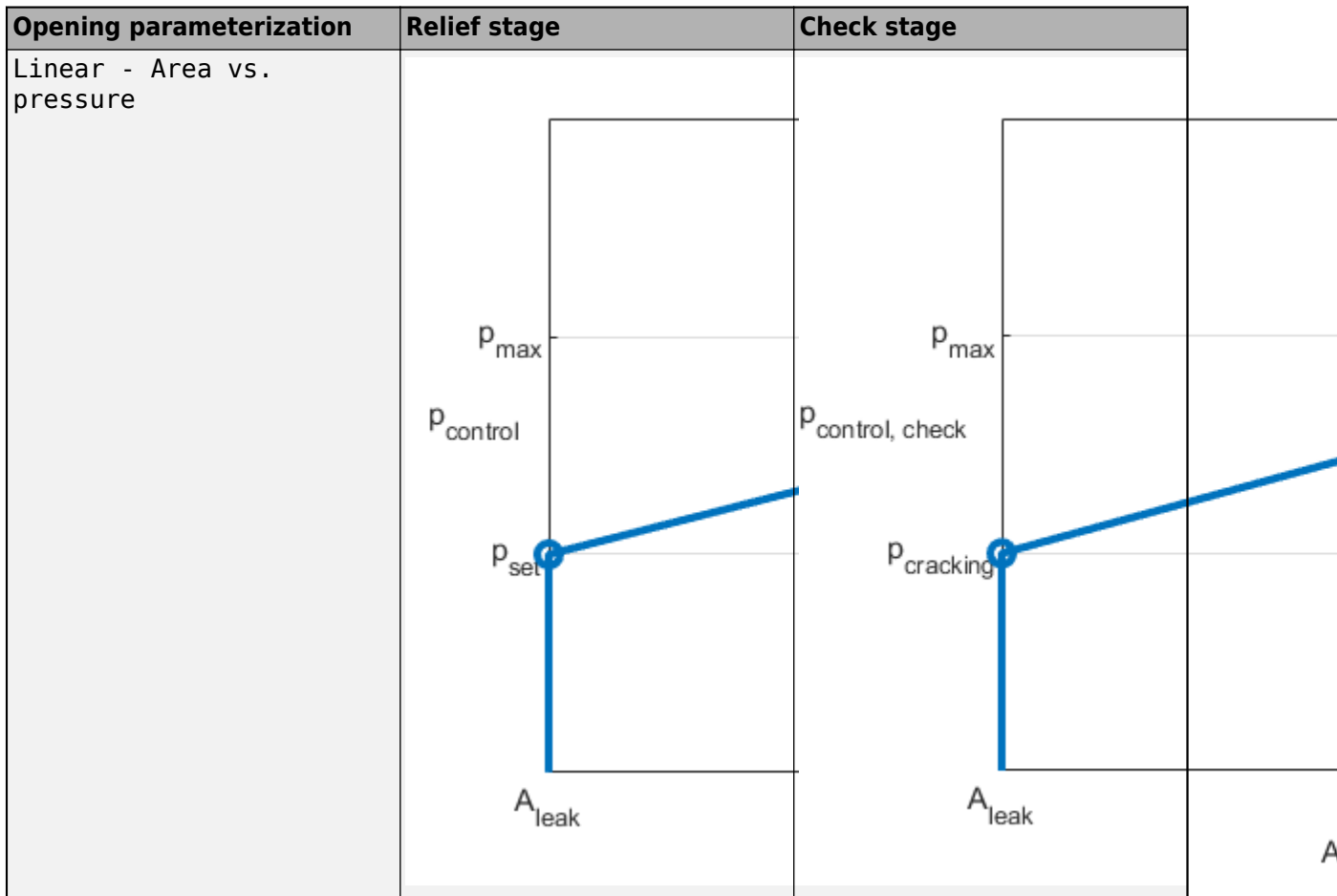
$$p_{back,Ref} = 1 \text{ atm}$$

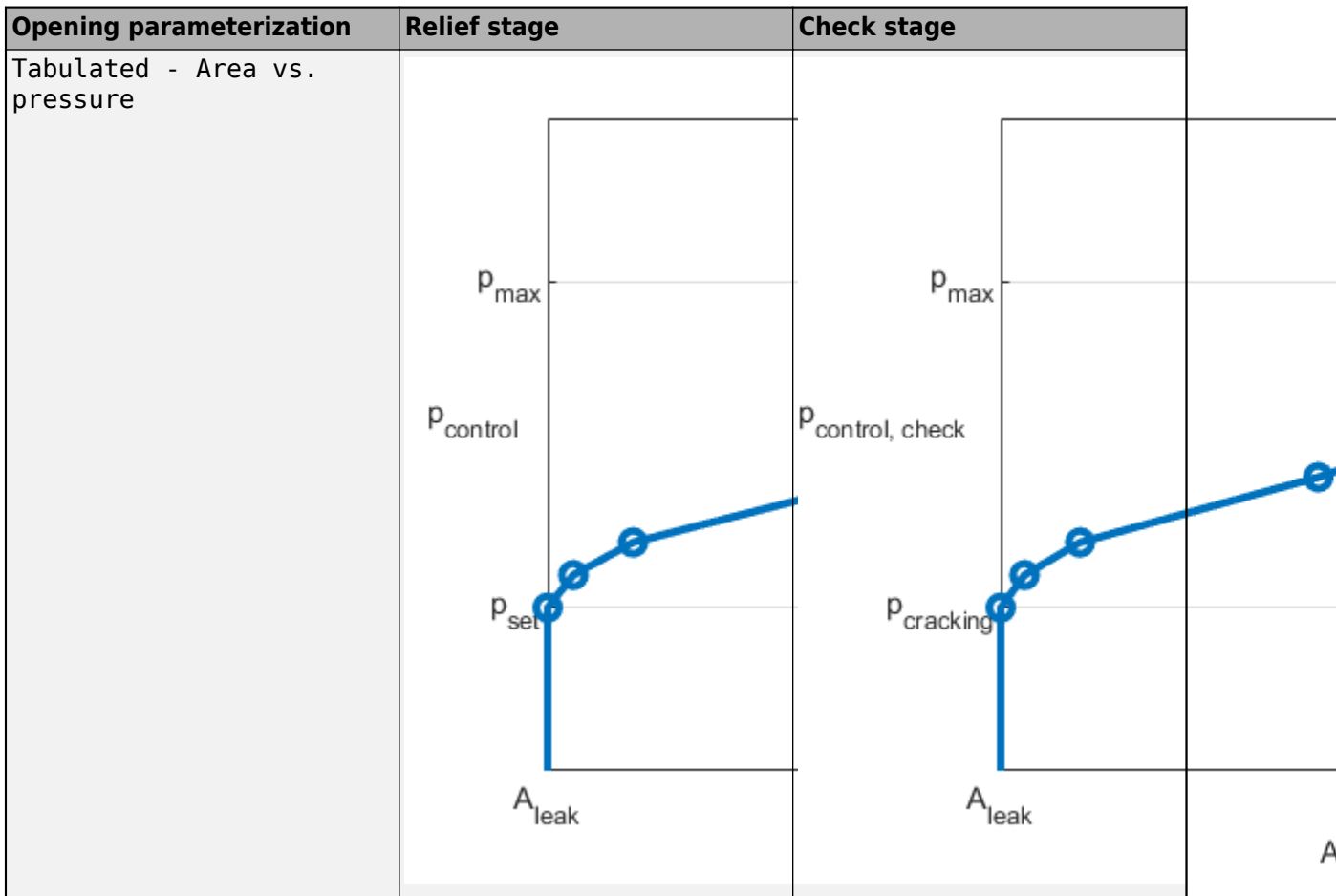
$$p_{load,Ref} = p_{back,Ref} + \Delta p_{valve,TLU,Ref}$$

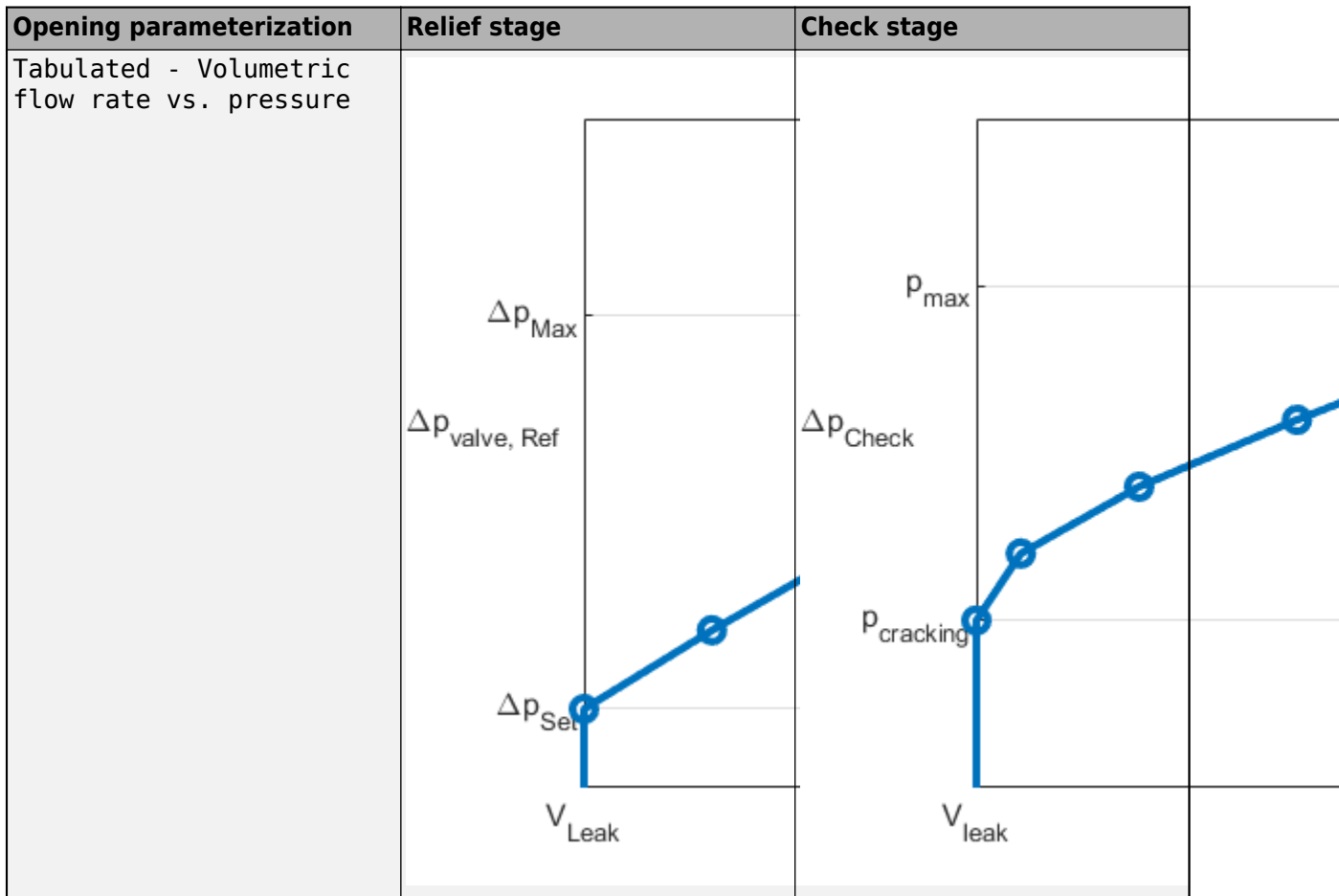
The block internally derives  $\Delta p_{flow,Ref}$  which is the pressure drop for fluid flow in the specified reference curve. The block calculates  $p_{offset}$  internally as

$$p_{offset} = p_{set} - R_{pilot} p_{pilot,Ref} - p_{load,Ref}(1) + R_{back} p_{back,Ref}$$

The table shows how the block controls the relief and check stages opening areas depending the **Opening area** parameter setting.







### Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

To learn more, see “List of Pre-Parameterized Components”.

## Assumptions and Limitations

- The block operates in only the internal drain-external pilot, non-vented configuration.
- When you set **Opening parameterization** to **Tabulated data - Volumetric flow rate vs. pressure**, the block uses values of volumetric flow rate with respect to the pressure drop across the relief stage to generate reference curves. The block assumes that the pilot port and back port are open to atmospheric pressure.

## Ports

### Conserving

#### **L – Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with the load.

#### **B – Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with the back pressure of the valve.

#### **P – Pressure port**

isothermal liquid

Pilot pressure port.

## Parameters

### Model Parameterization

#### **Opening parameterization – Opening parameterization**

Linear - Area vs. pressure (default) | Tabulated data - Area vs. pressure |  
Tabulated data - Volumetric flow rate vs. pressure

Method of modeling the opening of the valve. When you select **Linear - Area vs. pressure** or **Tabulated data - Area vs. pressure**, the block relates the opening area to the control pressure. When you select **Tabulated data - Volumetric flow rate vs. pressure**, the block takes a reference flow rate and pressure differential curve for the relief and check stages of the counterbalance valve, where the pressure at the back port and pilot port corresponds to 1 atm in the reference curve for the relief stage.

#### **Set pressure differential – Initial spring compression pressure**

5 MPa (default) | nonnegative scalar

Pressure differential to lift the relief stage. Use this parameter to adjust the set pressure supplied by the data sheet.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure or Tabulated data - Volumetric flow rate vs. pressure.

**Pressure differential vector — Relief stage pressure drop values**

5 : 0.2 : 6 MPa (default) | 1-by-n vector

Vector of pressure differential values for the relief stage. The vector elements must correspond one-to-one with the elements in the **Opening area vector** parameter. You must enter the elements in ascending order. This vector defines the control pressures that govern valve opening and shutting. The first element in the vector defines the set pressure, which is the control pressure when the relief stage just begins to open. The last element defines the control pressure for which the valve is fully open.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Area vs. pressure.

**Reference pressure differential vector — Pressure drop across relief stage**

5 : 0.2 : 6 MPa (default) | vector

Vector of pressure drops across the relief stage. The vector elements must correspond one-to-one with the elements in the **Reference volumetric flow rate vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Reference volumetric flow rate vector — Flow rate through relief stage**

[6.4e-09, .0013, .0027, .0041, .0055, .007] m<sup>3</sup>/s (default) | vector

Vector of flow rates through the relief stage. The vector elements must correspond one-to-one with the elements in the **Reference pressure differential vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Maximum opening pressure differential — Maximum relief valve pressure**

6 MPa (default) | positive scalar

The maximum relief valve pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

**Maximum opening area — Relief stage maximum open area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum open area of the relief stage orifice.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

**Leakage area — Gap area when valve is in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

**Pilot ratio — Pilot area ratio**

3 (default) | positive scalar

Ratio of the pressure-acting area of the pilot to the pressure-acting area of the load.

**Back pressure ratio — Back pressure area ratio**

4 (default) | positive scalar

Ratio of the back pressure pressure-acting area to the load pressure-acting area.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-shut positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Opening area vector — Relief stage opening areas**

[1e-10, 2e-05, 4e-05, 6e-05, 8e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of relief stage opening areas. The vector elements must correspond one-to-one with the elements in the **Pressure differential vector** parameter. List the elements in ascending order. All elements must be greater than 0.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Area vs. pressure.

**Opening dynamics — Whether to introduce flow lag due to orifice opening**

Off (default) | On



Whether to account for the transient effects to the fluid system due to opening the valve. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the pressure response. The **Opening time constant** parameter also impacts the modeled opening dynamics.

When enabled, these dynamics apply to the relief stage and not the check stage of the counterbalance valve.

#### **Opening time constant – Orifice opening time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state conditions when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

#### **Dependencies**

To enable this parameter, set **Opening dynamics** to On.

#### **Check Valve**

#### **Cracking pressure differential – Set pressure for check valve operation**

0.01 MPa (default) | positive scalar

Pressure differential that lifts the check valve.

#### **Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

#### **Maximum opening pressure differential – Maximum pressure in valve**

0.1 MPa (default) | positive scalar

Maximum valve pressure. This parameter bounds the pressures at the valve exit to maintain physical values during simulation.

#### **Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

#### **Maximum opening area – Maximum open area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum open area of the check valve in the load line. Internally, this check valve is in parallel with the relief stage.

#### **Dependencies**

To enable this parameter, set **Valve parameterization** to Linear - Area vs. pressure.

#### **Pressure differential vector – Pressure differential for check valve operation**

[0.01 : 0.01 : 0.1] MPa (default) | 1-by-n vector

Vector of pressure differentials for the check valve stage.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Area vs. pressure or Tabulated data - Volumetric flow rate vs. pressure.

**Opening area vector – Check stage opening areas**

[1e-10, 1e-05, 2e-05, 3e-05, 4e-05, 5e-05, 6e-05, 7.5e-05, 8.5e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the check valve stage. The vector elements must correspond one-to-one with the elements in the **Pressure differential vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Area vs. pressure.

**Volumetric flow rate vector – Check stage volumetric flow rates**

[.000358, .045, .11, .191, .284, .39, .505, .63, .764, .905] .\* 1e-3 m<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric flow rates for the check valve stage. The elements of this vector must correspond to the elements in the **Pressure differential vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

## Version History

Introduced in R2020a

**Opening parameterization options include volumetric flow rate**

You can set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure. This selection enables these new parameters:

- **Set pressure differential**
- **Reference pressure differential vector**
- **Reference volumetric flow rate vector**
- **Volumetric flow rate vector**

To improve clarity:

- The Linear option has been renamed to Linear - Area vs. pressure.
- The Tabulated option has been renamed to Tabulated data - Area vs. pressure

**Access pre-parameterized block options**

You can now select from available pre-parameterization options. Available manufacturers are Rexroth Bosch Group and Sun Hydraulics.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

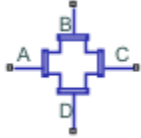
### **See Also**

[Check Valve \(IL\)](#) | [Pressure Compensator Valve \(IL\)](#) | [Pressure-Reducing 3-Way Valve \(IL\)](#) | [Pilot-Operated Check Valve \(IL\)](#) | [Shuttle Valve \(IL\)](#)

## Cross-Junction (IL)

Cross-junction in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Cross-Junction (IL) block represents a four-way junction in an isothermal liquid network. The block abstracts the fluid interactions depending on the direction of flow at each port, where ports **A** and **C** are the main line and ports **B** and **D** are the branch line. The block defines four unique flow configurations: diverging flow, converging flow, perpendicular flow, and colliding flow. All four configurations can occur in the same block during a simulation. You only need to supply parameters for each condition that the block experiences. The block conserves mass such that

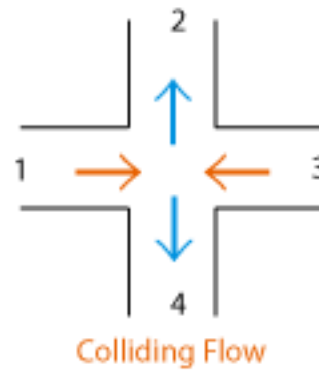
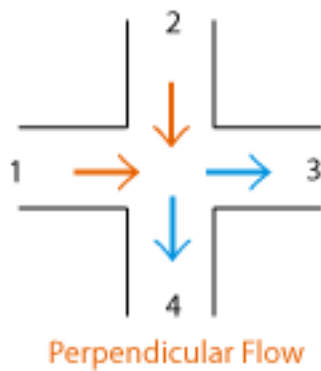
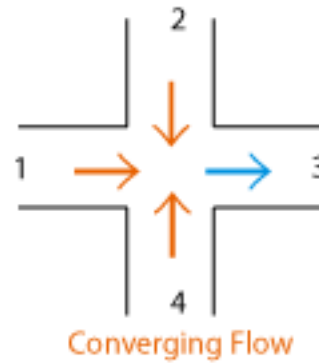
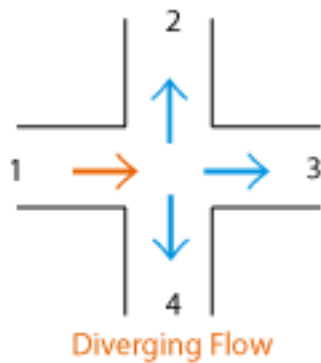
$$\dot{m}_A + \dot{m}_B + \dot{m}_C + \dot{m}_D = 0,$$

where  $\dot{m}_i$  is the mass flow rate for a given port,  $i$ .

The possible flow configurations are:

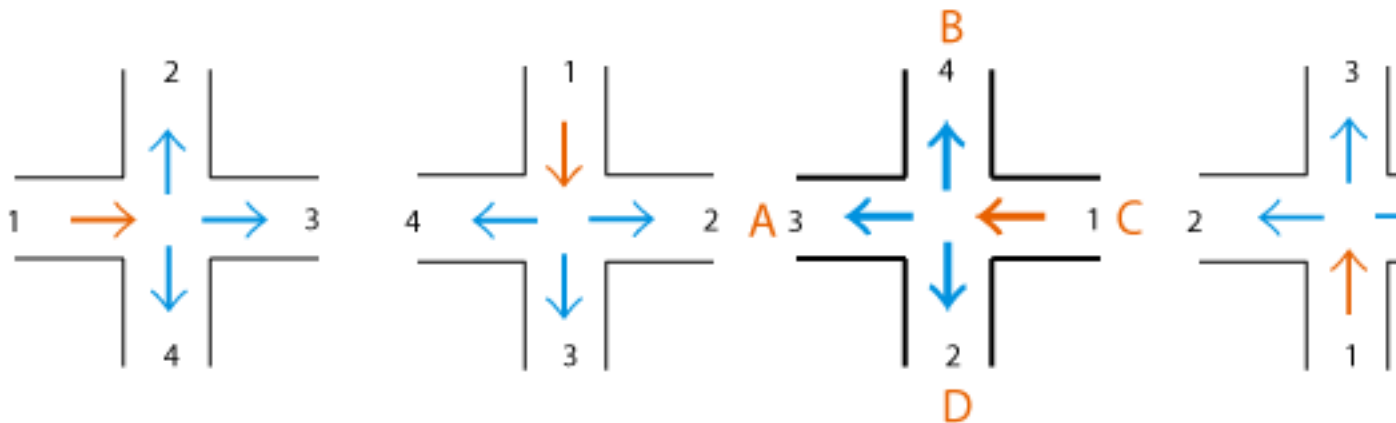
- Diverging flow — Flow enters at node 1 and exits at nodes 2, 3, and 4.
- Converging flow — Flow enters at nodes 1, 2, and 4 and exits at node 3.
- Perpendicular flow — Flow enters at nodes 1 and 2 and exits at nodes 3 and 4.
- Colliding flow — Flow enters at nodes 1 and 3 and exits at nodes 2 and 4.

This figure demonstrates these configurations.



The block takes advantage of simplifying assumptions to reduce the total number of parameters that you need to provide. The block treats the junction as symmetrical about both the horizontal and vertical planes such that  $A_1 = A_3$ , and  $A_2 = A_4$ , where  $A_{1,2,3,4}$  is the area of the corresponding port in the figure. Using this symmetry, the block assumes the loss coefficients from 1 to 2 and from 1 to 4 are identical during diverging, converging, and colliding flow.

During simulation, the block continually checks the direction of flow at each port and compares the result to the four possible flow configurations. When the block determines the flow configuration, it adjusts the node that each port corresponds to. For example, when the block experiences diverging flow where the fluid enters at port **C** and exits at ports **A**, **B**, and **D**, it assigns node 1 to port **C** as in the figure.



If you use two-element vectors to specify the flow coefficients, the block uses the first or second element depending on whether node 1 aligns with the main line or the branch line. The first element corresponds to node 1 at port **A** or **C**, and the second element corresponds to node 1 at port **B** or **D**. The block determines which coefficient and which vector element to use, then computes the pressure difference to conserve momentum such that

$$p_i - p_1 = I_i + \frac{k_i/2 \dot{m}_i \sqrt{\dot{m}_i^2 + \dot{m}_{threshold}^2}}{\bar{\rho} A_i^2},$$

where:

- $\bar{\rho}$  is the average fluid density.
- $p_i$  is the pressure for a given port,  $i$ .
- $p_1$  is the pressure at node 1.
- $k_i$  is the flow coefficient that the block assigns to a given port,  $i$ . This value can be either the turning flow or straight flow coefficient, depending on the port.
- $I_i$  is the fluid inertia for a given port,  $i$ .

The block calculates the inertia for each port as

$$I_A = \dot{m}_A \frac{\sqrt{\pi A_{side}}}{A_{main}}$$

$$I_B = \dot{m}_B \frac{\sqrt{\pi A_{main}}}{A_{side}}$$

$$I_C = \dot{m}_C \frac{\sqrt{\pi A_{side}}}{A_{main}}$$

$$I_D = \dot{m}_D \frac{\sqrt{\pi A_{main}}}{A_{side}}$$

The block uses mode charts to determine the value of  $k_i$ . This table describes the conditions and coefficients for each operational mode.

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$\dot{m}_D$	$k_A$	$k_B$	$k_C$	$k_D$
Diverging from node A	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{div,turning,main}$	$k_{div,straight,main}$	$k_{div,turning,main}$
Diverging from node B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{div,turning,side}$	0	$k_{div,turning,side}$	$k_{div,straight,side}$
Diverging from node C	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{div,straight,main}$	$k_{div,turning,main}$	0	$k_{div,turning,main}$
Diverging from node D	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{div,turning,side}$	$k_{div,straight,side}$	$k_{div,turning,side}$	0
Converging to node A	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	0	$k_{conv,turning,main}$	$k_{conv,straight,main}$	$k_{conv,turning,main}$
Converging to node B	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{conv,turning,side}$	0	$k_{conv,turning,side}$	$k_{conv,straight,side}$
Converging to node C	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{conv,straight,main}$	$k_{conv,turning,main}$	0	$k_{conv,turning,main}$
Converging to node D	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{conv,turning,side}$	$k_{conv,straight,side}$	$k_{conv,turning,side}$	0
Perpendicular with main entry A	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{perp,turning,in,main}$	$k_{perp,straight,main}$	$k_{perp,turning,out,main}$
Perpendicular with main entry B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{perp,turning,out,side}$	0	$k_{perp,turning,in,side}$	$k_{perp,turning,straight,side}$
Perpendicular with main entry C	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{perp,straight,main}$	$k_{perp,turning,out,main}$	0	$k_{perp,turning,in,main}$
Perpendicular with main entry D	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{perp,turning,in,side}$	$k_{perp,turning,straight,side}$	$k_{perp,turning,out,side}$	0
Colliding from main to branch	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{coll,turning,main}$	$k_{coll,straight,main}$	$k_{coll,turning,main}$

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$\dot{m}_D$	$k_A$	$k_B$	$k_C$	$k_D$
Colliding from branch to main	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{coll,turning,side}$	0	$k_{coll,turning,side}$	$k_{coll,straight,side}$
Stagnant	-	-	-	-	1 or last valid	1 or last valid	1 or last valid	1 or last valid

The flow is stagnant when the mass flow rate conditions do not match any defined flow scenario. The block uses these parameters to calculate the flow coefficients.

- $k_{div,straight,main}$  and  $k_{div,straight,side}$  are the first and second elements **Diverging flow straight loss coefficient** parameter, respectively.
- $k_{div,turning,main}$  and  $k_{div,turning,side}$  are the first and second elements **Diverging flow turning loss coefficient** parameter, respectively.
- $k_{conv,straight,main}$  and  $k_{conv,straight,side}$  are the first and second elements **Converging flow straight loss coefficient** parameter, respectively.
- $k_{conv,turning,main}$  and  $k_{conv,turning,side}$  are the first and second elements **Converging flow turning loss coefficient** parameter, respectively.
- $k_{perp,straight,main}$  and  $k_{perp,straight,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{perp,turning\ in,main}$  and  $k_{perp,turning\ in,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{perp,turning\ out,main}$  and  $k_{perp,turning\ out,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{coll,straight,main}$  and  $k_{coll,straight,side}$  are the first and second elements **Colliding flow straight loss coefficient** parameter, respectively.
- $k_{coll,turning,main}$  and  $k_{coll,turning,side}$  are the first and second elements **Colliding flow turning loss coefficient** parameter, respectively.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Isothermal liquid conserving port.

#### B – Liquid port

isothermal liquid

Isothermal liquid conserving port.

#### C – Liquid port

isothermal liquid

Isothermal liquid conserving port.



**D – Liquid port**

isothermal liquid

Isothermal liquid conserving port.

**Parameters****Junction Properties****Main line area (A,C) – Area of main path**0.01 m<sup>2</sup> (default) | positive scalarCross-sectional area of the main flow path from port **A** to port **C**.**Branch line area (B,D) – Area of branch path**0.01 m<sup>2</sup> (default) | positive scalarCross-sectional area of the branch flow path from port **B** to port **D**.**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the junction.

**Diverging flow loss coefficients – Option to specify loss coefficients for diverging flow**

On (default) | Off

Whether to specify loss coefficients for diverging flow.

**Converging flow loss coefficients – Option to specify loss coefficients for converging flow**

On (default) | Off

Whether to specify loss coefficients for converging flow.

**Perpendicular flow loss coefficients – Option to specify loss coefficients for perpendicular flow**

Off (default) | On

Whether to specify loss coefficients for perpendicular flow.

**Colliding flow loss coefficients – Option to specify loss coefficients for colliding flow**

Off (default) | On

Whether to specify loss coefficients for colliding flow.

**Diverging Flow Coefficients****Diverging flow straight loss coefficient – Diverging flow straight loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the straight portion of the diverging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1.

The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Diverging flow loss coefficients** parameter.

**Diverging flow turning loss coefficient – Diverging flow turning loss coefficient**  
[ 1.12, 1.12 ] (default) | positive scalar or vector

Loss coefficient for the turning portions of the diverging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Diverging flow loss coefficients** parameter.

**Converging Flow Coefficients**

**Converging flow straight loss coefficient – Converging flow straight loss coefficient**  
[ 1.12, 1.12 ] (default) | positive scalar or vector

Loss coefficient for the straight portion of the converging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Converging flow loss coefficients** parameter.

**Converging flow turning loss coefficient – Converging flow turning loss coefficient**  
[ 1.12, 1.12 ] (default) | positive scalar or vector

Loss coefficient for the turning portions of the converging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Converging flow loss coefficients** parameter.

**Perpendicular Flow Coefficients**

**Perpendicular flow turning to inflow loss coefficient – Perpendicular flow turning to inflow loss coefficient**  
[ 1.12, 1.12 ] (default) | positive scalar or vector

Loss coefficient for the flow turning to inflow in the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Perpendicular flow turning to outflow loss coefficient – Perpendicular flow turning to outflow loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the flow turning to outflow in the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Perpendicular flow straight loss coefficient – Perpendicular flow straight loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the straight portion of the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Colliding Flow Coefficients****Colliding flow turning loss coefficient – Colliding flow turning loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portion of the colliding flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Colliding flow loss coefficients** parameter.

**Colliding flow straight loss coefficient – Colliding flow straight loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portion of the colliding flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Colliding flow loss coefficients** parameter.

## **Version History**

**Introduced in R2022b**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

T-Junction (IL) | Cross-Junction (TL)

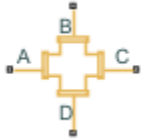
#### **Topics**

“Mode Chart Modeling”

## Cross-Junction (TL)

Cross-junction in a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Pipes & Fittings



### Description

The Cross-Junction (TL) block represents a four-way junction in an thermal liquid network. The block abstracts the fluid interactions depending on the direction of flow at each port, where ports **A** and **C** are the main line and ports **B** and **D** are the branch line. The block defines four unique flow configurations: diverging flow, converging flow, perpendicular flow, and colliding flow. All four configurations can occur in the same block during a simulation. You only need to supply parameters for each condition that the block experiences. The block conserves mass such that

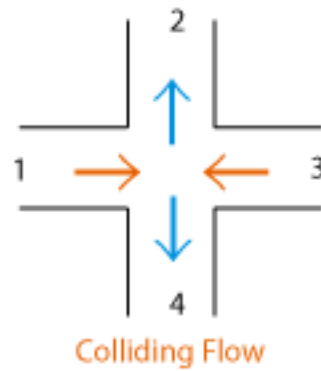
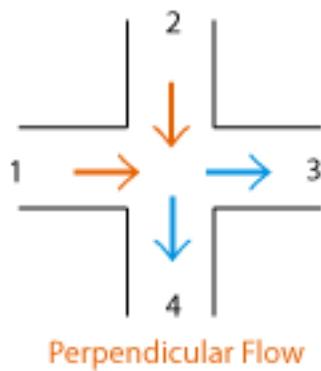
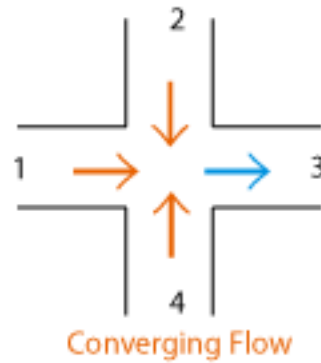
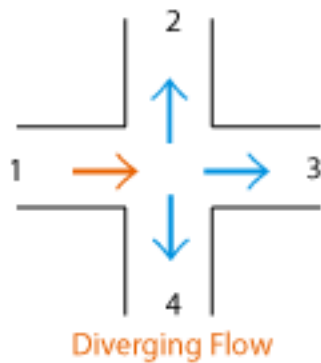
$$\dot{m}_A + \dot{m}_B + \dot{m}_C + \dot{m}_D = 0,$$

where  $\dot{m}_i$  is the mass flow rate for a given port,  $i$ .

The possible flow configurations are:

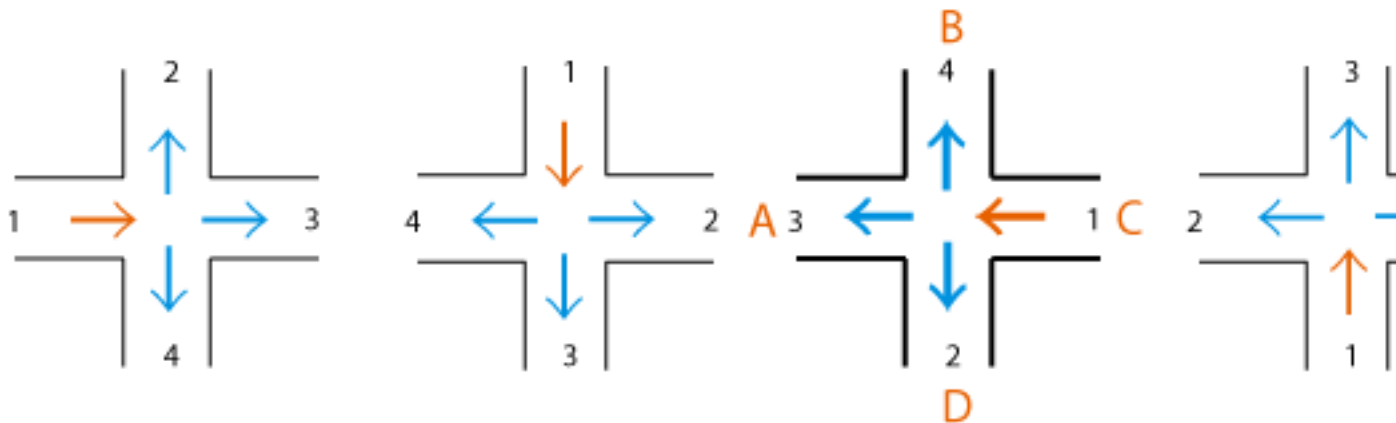
- Diverging flow — Flow enters at node 1 and exits at nodes 2, 3, and 4.
- Converging flow — Flow enters at nodes 1, 2, and 4 and exits at node 3.
- Perpendicular flow — Flow enters at nodes 1 and 2 and exits at nodes 3 and 4.
- Colliding flow — Flow enters at nodes 1 and 3 and exits at nodes 2 and 4.

This figure demonstrates these configurations.



The block takes advantage of simplifying assumptions to reduce the total number of parameters that you need to provide. The block treats the junction as symmetrical about both the horizontal and vertical planes such that  $A_1 = A_3$ , and  $A_2 = A_4$ , where  $A_{1,2,3,4}$  is the area of the corresponding port in the figure. Using this symmetry, the block assumes the loss coefficients from 1 to 2 and from 1 to 4 are identical during diverging, converging, and colliding flow.

During simulation, the block continually checks the direction of flow at each port and compares the result to the four possible flow configurations. When the block determines the flow configuration, it adjusts the node that each port corresponds to. For example, when the block experiences diverging flow where the fluid enters at port **C** and exits at ports **A**, **B**, and **D**, it assigns node 1 to port **C** as in the figure.



If you use two-element vectors to specify the flow coefficients, the block uses the first or second element depending on whether node 1 aligns with the main line or the branch line. The first element corresponds to node 1 at port **A** or **C**, and the second element corresponds to node 1 at port **B** or **D**. The block determines which coefficient and which vector element to use, then computes the pressure difference to conserve momentum such that

$$p_i - p_1 = I_i + \frac{k_i/2 \dot{m}_i \sqrt{\dot{m}_i^2 + \dot{m}_{threshold}^2}}{\bar{\rho} A_i^2},$$

where:

- $\bar{\rho}$  is the average fluid density.
- $p_i$  is the pressure for a given port,  $i$ .
- $p_1$  is the pressure at node 1.
- $k_i$  is the flow coefficient that the block assigns to a given port,  $i$ . This value can be either the turning flow or straight flow coefficient, depending on the port.
- $I_i$  is the fluid inertia for a given port,  $i$ .

The block calculates the inertia for each port as

$$I_A = \dot{m}_A \frac{\sqrt{\pi A_{side}}}{A_{main}}$$

$$I_B = \dot{m}_B \frac{\sqrt{\pi A_{main}}}{A_{side}}$$

$$I_C = \dot{m}_C \frac{\sqrt{\pi A_{side}}}{A_{main}}$$

$$I_D = \dot{m}_D \frac{\sqrt{\pi A_{main}}}{A_{side}}$$

The block uses mode charts to determine the value of  $k_i$ . This table describes the conditions and coefficients for each operational mode.

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$\dot{m}_D$	$k_A$	$k_B$	$k_C$	$k_D$
Diverging from node A	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{div,turning,main}$	$k_{div,straight,main}$	$k_{div,turning,main}$
Diverging from node B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{div,turning,side}$	0	$k_{div,turning,side}$	$k_{div,straight,side}$
Diverging from node C	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{div,straight,main}$	$k_{div,turning,main}$	0	$k_{div,turning,main}$
Diverging from node D	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{div,turning,side}$	$k_{div,straight,side}$	$k_{div,turning,side}$	0
Converging to node A	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	0	$k_{conv,turning,main}$	$k_{conv,straight,main}$	$k_{conv,turning,main}$
Converging to node B	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{conv,turing,side}$	0	$k_{conv,turing,side}$	$k_{conv,straight,side}$
Converging to node C	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{conv,straight,main}$	$k_{conv,turning,main}$	0	$k_{conv,turning,main}$
Converging to node D	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{conv,turing,side}$	$k_{conv,straight,side}$	$k_{conv,turing,side}$	0
Perpendicular with main entry A	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{perp,turning,in,main}$	$k_{perp,straight,main}$	$k_{perp,turning,out,main}$
Perpendicular with main entry B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$k_{perp,turning,out,side}$	0	$k_{perp,turning,in,side}$	$k_{perp,turning,straight,side}$
Perpendicular with main entry C	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{perp,straight,main}$	$k_{perp,turning,out,main}$	0	$k_{perp,turning,in,main}$
Perpendicular with main entry D	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{perp,turning,in,side}$	$k_{perp,turning,straight,side}$	$k_{perp,turning,out,side}$	0
Colliding from main to branch	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$k_{coll,turning,main}$	$k_{coll,straight,main}$	$k_{coll,turning,main}$



Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$\dot{m}_D$	$k_A$	$k_B$	$k_C$	$k_D$
Colliding from branch to main	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$k_{coll,turning,side}$	0	$k_{coll,turning,side}$	$k_{coll,straight,side}$
Stagnant	-	-	-	-	1 or last valid	1 or last valid	1 or last valid	1 or last valid

The flow is stagnant when the mass flow rate conditions do not match any defined flow scenario. The block uses these parameters to calculate the flow coefficients.

- $k_{div,straight,main}$  and  $k_{div,straight,side}$  are the first and second elements **Diverging flow straight loss coefficient** parameter, respectively.
- $k_{div,turning,main}$  and  $k_{div,turning,side}$  are the first and second elements **Diverging flow turning loss coefficient** parameter, respectively.
- $k_{conv,straight,main}$  and  $k_{conv,straight,side}$  are the first and second elements **Converging flow straight loss coefficient** parameter, respectively.
- $k_{conv,turning,main}$  and  $k_{conv,turning,side}$  are the first and second elements **Converging flow turning loss coefficient** parameter, respectively.
- $k_{perp,straight,main}$  and  $k_{perp,straight,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{perp,turning\ in,main}$  and  $k_{perp,turning\ in,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{perp,turning\ out,main}$  and  $k_{perp,turning\ out,side}$  are the first and second elements **Perpendicular flow straight loss coefficient** parameter, respectively.
- $k_{coll,straight,main}$  and  $k_{coll,straight,side}$  are the first and second elements **Colliding flow straight loss coefficient** parameter, respectively.
- $k_{coll,turning,main}$  and  $k_{coll,turning,side}$  are the first and second elements **Colliding flow turning loss coefficient** parameter, respectively.

The block conserves energy such that

$$\varphi_A + \varphi_B + \varphi_C + \varphi_D = 0.$$

## Ports

### Conserving

#### A – Liquid port

thermal liquid

Thermal liquid conserving port.

#### B – Liquid port

thermal liquid

Thermal liquid conserving port.

**C – Liquid port**

thermal liquid

Thermal liquid conserving port.

**D – Liquid port**

thermal liquid

Thermal liquid conserving port.

**Parameters****Junction Properties****Main line area (A,C) – Area of main path**0.01 m<sup>2</sup> (default) | positive scalarCross-sectional area of the main flow path from port **A** to port **C**.**Branch line area (B,D) – Area of branch path**0.01 m<sup>2</sup> (default) | positive scalarCross-sectional area of the branch flow path from port **B** to port **D**.**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the junction.

**Diverging flow loss coefficients – Option to specify loss coefficients for diverging flow**

On (default) | Off

Whether to specify loss coefficients for diverging flow.

**Converging flow loss coefficients – Option to specify loss coefficients for converging flow**

On (default) | Off

Whether to specify loss coefficients for converging flow.

**Perpendicular flow loss coefficients – Option to specify loss coefficients for perpendicular flow**

Off (default) | On

Whether to specify loss coefficients for perpendicular flow.

**Colliding flow loss coefficients – Option to specify loss coefficients for colliding flow**

Off (default) | On

Whether to specify loss coefficients for colliding flow.

## Diverging Flow Coefficients

**Diverging flow straight loss coefficient – Diverging flow straight loss coefficient**  
[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the straight portion of the diverging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

### Dependencies

To enable this parameter, select the **Diverging flow loss coefficients** parameter.

**Diverging flow turning loss coefficient – Diverging flow turning loss coefficient**  
[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portions of the diverging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

### Dependencies

To enable this parameter, select the **Diverging flow loss coefficients** parameter.

## Converging Flow Coefficients

**Converging flow straight loss coefficient – Converging flow straight loss coefficient**  
[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the straight portion of the converging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

### Dependencies

To enable this parameter, select the **Converging flow loss coefficients** parameter.

**Converging flow turning loss coefficient – Converging flow turning loss coefficient**  
[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portions of the converging flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

### Dependencies

To enable this parameter, select the **Converging flow loss coefficients** parameter.

## Perpendicular Flow Coefficients

**Perpendicular flow turning to inflow loss coefficient – Perpendicular flow turning to inflow loss coefficient**  
[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the flow turning to inflow in the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Perpendicular flow turning to outflow loss coefficient – Perpendicular flow turning to outflow loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the flow turning to outflow in the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Perpendicular flow straight loss coefficient – Perpendicular flow straight loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the straight portion of the perpendicular flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Perpendicular flow loss coefficients** parameter.

**Colliding Flow Coefficients****Colliding flow turning loss coefficient – Colliding flow turning loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portion of the colliding flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Colliding flow loss coefficients** parameter.

**Colliding flow straight loss coefficient – Colliding flow straight loss coefficient**

[1.12, 1.12] (default) | positive scalar or vector

Loss coefficient for the turning portion of the colliding flow. When you specify this parameter as a vector, the first element represents the loss coefficient when ports **A** or **C** align to reference node 1. The second element represents when ports **B** or **D** align to reference node 1. The block behaves the same for all orientations when you use a scalar.

**Dependencies**

To enable this parameter, select the **Colliding flow loss coefficients** parameter.

**Version History**

**Introduced in R2022b**

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

T-Junction (TL) | Cross-Junction (IL)

**Topics**

“Mode Chart Modeling”

# Cylinder Cushion

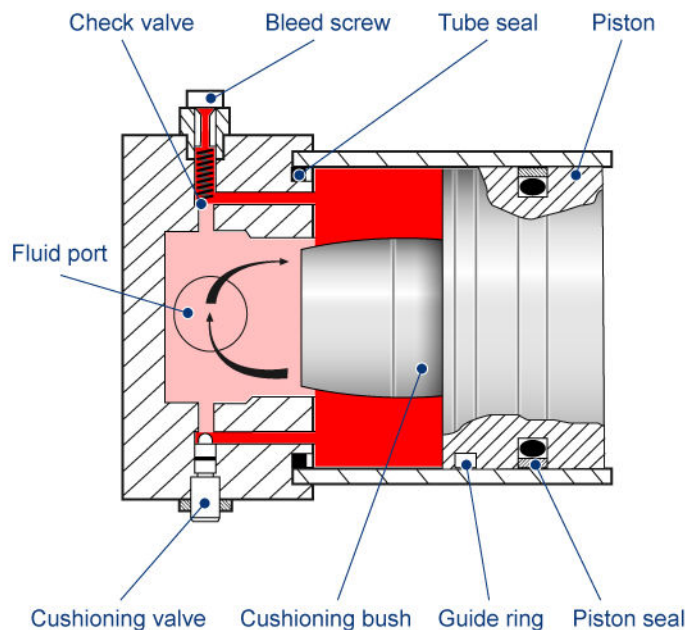
Cushion in hydraulic cylinders

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Hydraulic Cylinders



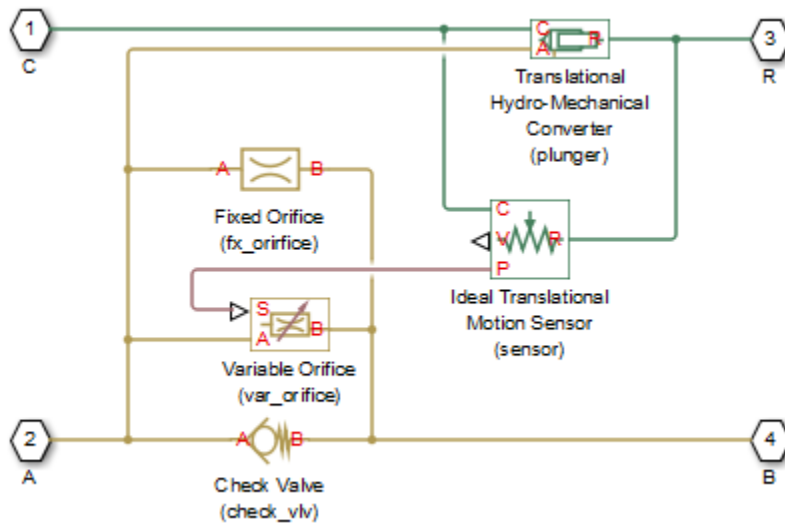
## Description

The Cylinder Cushion block models a hydraulic cylinder cushion, the device that decelerates the cylinder rod near the end of the stroke by restricting the flow rate leaving the cylinder chamber. The figure shows a typical design of a cylinder cushion [1] on page 1-662.



As the piston moves toward the cap (to the left in the figure), the cushioning bush enters the chamber in the cap and creates an additional resistance to the fluid leaving the chamber. The bush profile determines the desired deceleration. Near the end of the stroke, the fluid flows through the gap between the bush and the cap and through the cushioning valve with constant cross-sectional area. The check valve located between the chambers allows free flow to the piston chamber to ease the piston breakaway from the end position.

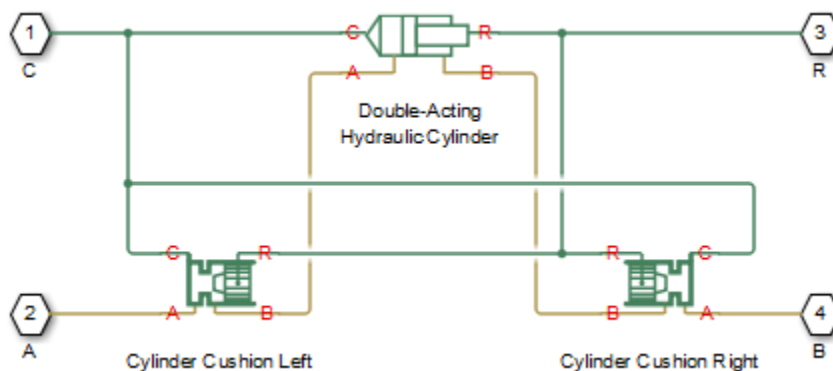
The block is implemented as a structural model that replicates a cushioning device, as shown in this diagram.



The Variable Orifice block represents a variable gap between the bush and the cavity machined in the end cap. The lookup table of the Variable Orifice block implements the relationship between the orifice area and the piston displacement. The Fixed Orifice and the Check Valve blocks simulate the cushioning valve and the check valve installed between chambers. The Translational Hydro-Mechanical Converter represents a plunger created by the bush and the cavity. The Ideal Translational Motion Sensor block monitors the piston displacement and conveys it (with the initial piston position accounted) to the Variable Orifice block. The names assigned to the nested blocks in the model are shown in parentheses.

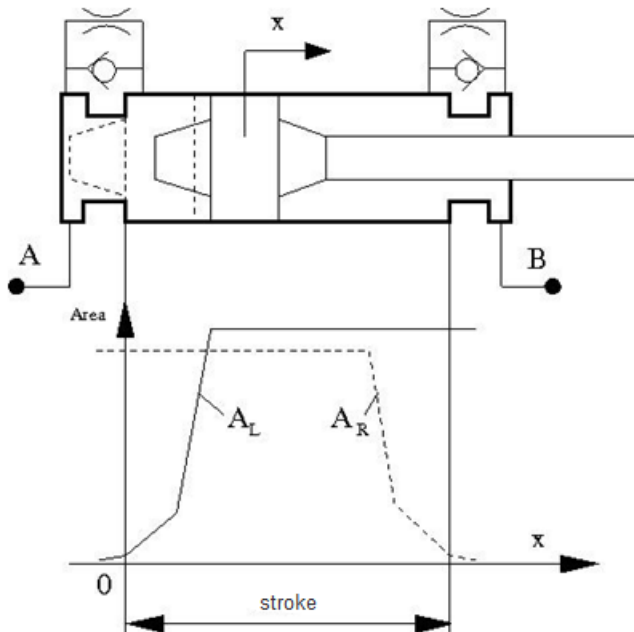
The block develops a cushioning effect for the flow rate from port B to port A. The check valve in the block is oriented from port **A** to port **B**.

You can use this block with any of the cylinder blocks in the library to model a single-acting or double-acting cylinder with cushion. The following diagram shows the model of a double-sided hydraulic cylinder with cushion built from a Double-Acting Hydraulic Cylinder block and two Cylinder Cushion blocks.



You can adjust the cushioning effect by changing the area of the fixed orifice and the profile of the cushioning bush (variable orifice). Specify the profile using the one-dimensional lookup table of the orifice area versus piston displacement. The next figure shows a typical configuration of a double-

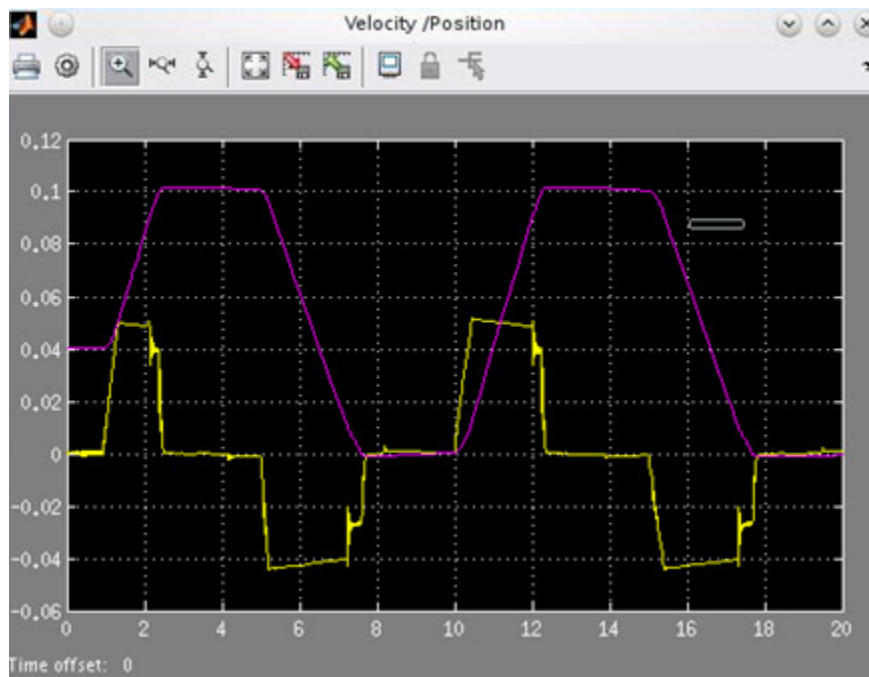
acting cylinder with the double-sided cushioning, similar to the model shown in the block diagram above.



To ensure cushioning on both sides of the stroke, set the variable orifice area of the left cushion ( $A_L$ ) and the right cushion ( $A_R$ ) similar to the profile shown in the figure. The origin of the plot is located at the position where the piston touches the cap. If the cylinder acts in the negative direction, the piston displacements are negative, and you must make the profile specification in the fourth quadrant.

The following figure shows a typical motion diagram of a cylinder with the double-sided cushioning.





The cushions are set to provide deceleration at  $\sim 10$  mm before the end of the stroke. The stroke of the cylinder is 10 cm, and the initial position of the piston is 0.04 m. The plot shows the velocity (yellow line) and motion (magenta line) profiles.

Connections **A** and **B** are hydraulic conserving ports associated with the device hydraulic inlet and outlet. Connection **R** is a mechanical translational conserving port that connects to the cylinder rod. Connection **C** is a mechanical translational conserving port that connects to the cylinder clamping structure.

## Ports

### Conserving

#### **A – Cylinder inlet**

isothermal liquid

Hydraulic conserving port connected to the cylinder inlet.

#### **B – Cylinder outlet**

isothermal liquid

Hydraulic conserving port connected to the cylinder outlet.

#### **R – Rod**

isothermal liquid

Mechanical translational conserving port connected to the cylinder rod.

#### **C – Mechanical reference**

isothermal liquid

Mechanical translational conserving port connected to the cylinder clamping structure.

## Parameters

### Cushion piston

#### **Cushion piston area — Cross-sectional area**

1e-4 m<sup>2</sup> (default) | positive scalar

Addition of the cushion to a cylinder converts the respective cylinder into two cylinders, rigidly connected and acting in parallel, with the total effective area equal to the piston area before addition. This parameter sets the area of the cushion piston, which is the face area of the cushion bush.

#### **Piston initial displacement — Piston initial offset from cap A**

0 (default) | positive scalar

The distance between the cylinder piston and cap A at the start of simulation. The default value is 0, which corresponds to the fully retracted position of the piston.

#### **Piston orientation — Piston direction of movement**

Acts in positive direction (default) | Acts in negative direction

Piston orientation with respect to the globally assigned positive direction. Since the cushion piston is part of the cylinder piston, its orientation must be the same as the orientation of the cylinder piston at the side the cushion is attached to. Similar to a cylinder model, if pressure applied at port A exerts force in the negative direction, set the parameter to Acts in negative direction.

### Fixed orifice

#### **Fixed orifice area — Cross-sectional open area**

1e-6 m<sup>2</sup> (default)

The area of the fixed orifice installed between cushion chambers.

#### **Fixed orifice flow discharge coefficient — Discharge coefficient for fixed orifice**

0.7 (default) | positive scalar

Semi-empirical coefficient that is used in the computation of flow rate through the fixed orifice.

#### **Fixed orifice critical Reynolds number — Transition Reynolds number for fixed orifices**

10 (default) | positive scalar

The maximum Reynolds number for laminar flow through the fixed orifice. The transition from laminar to turbulent regime is supposed to take place when the Reynolds number reaches this value. The value of the parameter depends on the orifice geometrical profile. You can find the recommendations on the parameter value in hydraulic textbooks.

### Variable orifice

#### **Tabulated piston displacements — Piston displacement for tabular parameterization of orifice area**

[-2, 10, 11, 89, 90, 102] mm (default)

Vector of input values for piston displacements, specified as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The **Tabulated piston displacements** values are used together with **Tabulated orifice area** values for one-dimensional table lookup. Due to the nature of the cylinder hard stops, the piston can move below zero and above the stroke value. It is good practice to account for piston deformation and provide piston displacements beyond the ideal stroke range to avoid extrapolation.

#### **Tabulated orifice area — Orifice area for tabular parameterization of orifice area**

[.004, .006, 9, 9, 9, 9] cm<sup>2</sup> (default)

Vector of orifice areas, specified as a one-dimensional array. The vector must be the same size as the piston displacements vector. All the values must be positive.

#### **Variable orifice interpolation method — Tabular interpolation**

Linear (default) | Smooth

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

#### **Variable orifice extrapolation method — Tabular extrapolation**

Linear (default) | Nearest

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page.

#### **Variable orifice flow discharge coefficient — Discharge coefficient for variable orifices**

0.7 (default) | positive scalar

Semi-empirical coefficient that is used in the computation of flow rate through the variable orifice.

#### **Variable orifice critical Reynolds number — Transition Reynolds number for variable orifices**

10 (default) | positive scalar

The maximum Reynolds number for laminar flow through the variable orifice. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value.

The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks.

**Variable orifice leakage area – Open area when orifice is in fully closed position**

1e-12 m<sup>2</sup> (default) | positive scalar

The total area of possible leaks in the completely closed orifice. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0.

**Check valve****Check valve maximum area – Maximum open area**

1e-4 m<sup>2</sup> (default) | positive scalar

Valve passage maximum cross-sectional area. The default value is 1e-4 m<sup>2</sup>.

**Check valve cracking pressure – Threshold operating pressure**

0.5e5 Pa (default) | positive scalar

Pressure level at which the orifice of the valve starts to open.

**Check valve full opening pressure – Pressure that fully opens the valve**

1.5e5 Pa (default)

Pressure differential across the valve needed to fully open the valve. Its value must be higher than the cracking pressure.

**Check valve flow discharge coefficient – Discharge coefficient**

0.7 (default) | positive scalar

Semi-empirical coefficient that is used in the computation of flow rate through the check valve.

**Check valve critical Reynolds number – Transition Reynolds number for check valve flows**

10 (default) | positive scalar

The maximum Reynolds number for laminar flow through the check valve. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value.

**Check valve leakage area – Open area when valve is fully closed**

1e-12 m<sup>2</sup> (default) | positive scalar

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0.

## Version History

Introduced in R2013b

## References

[1] Rohner, P. *Industrial Hydraulic Control*. Fourth edition. Brisbane : John Wiley & Sons, 1995.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Check Valve | Fixed Orifice | Variable Orifice

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Cylinder Cushion (IL)

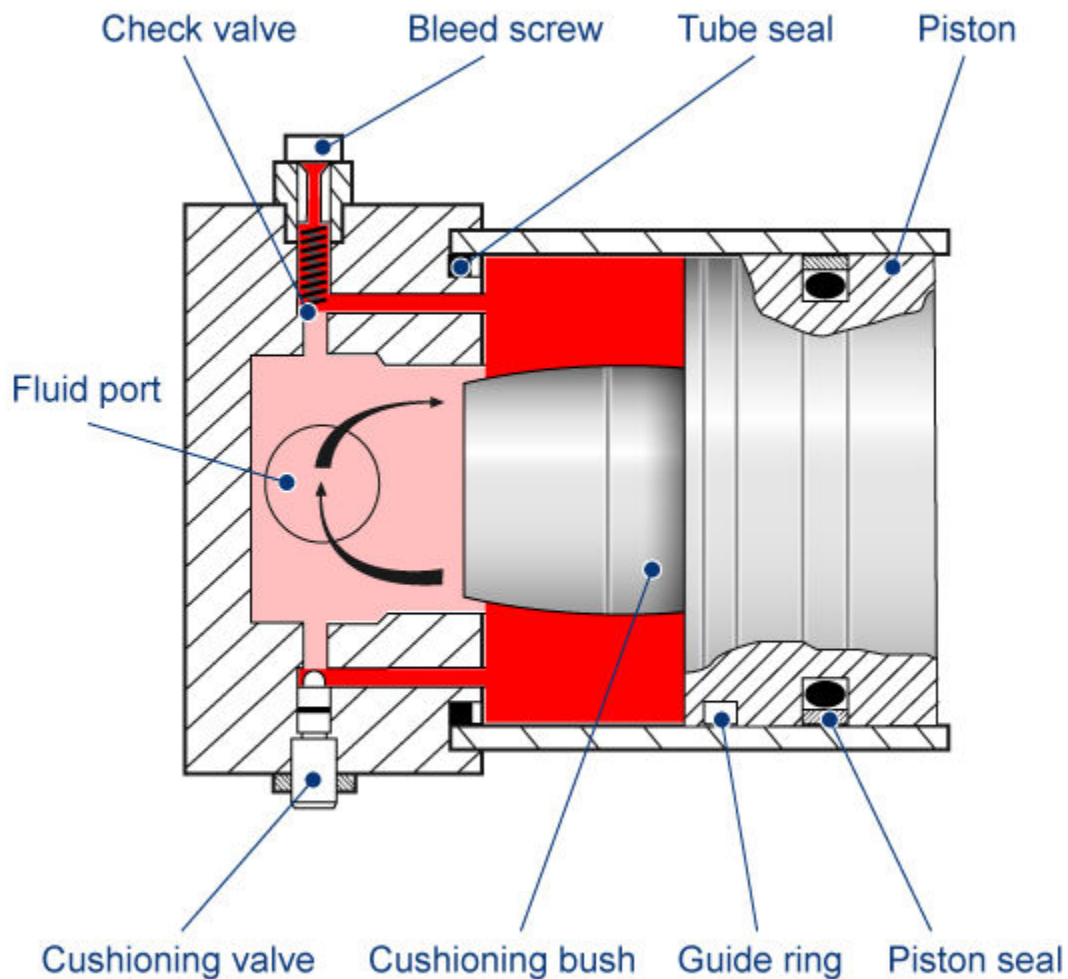
Cushion in cylinder in isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators / Auxiliary Components



### Description

The Cylinder Cushion (IL) block models a cylinder cushion in an isothermal liquid network. The cushion decelerates the cylinder rod as it approaches the end of a stroke by restricting the flow rate leaving the cylinder chamber. This figure below shows a typical cylinder cushion design [1].



**Typical Cylinder Cushion Design**

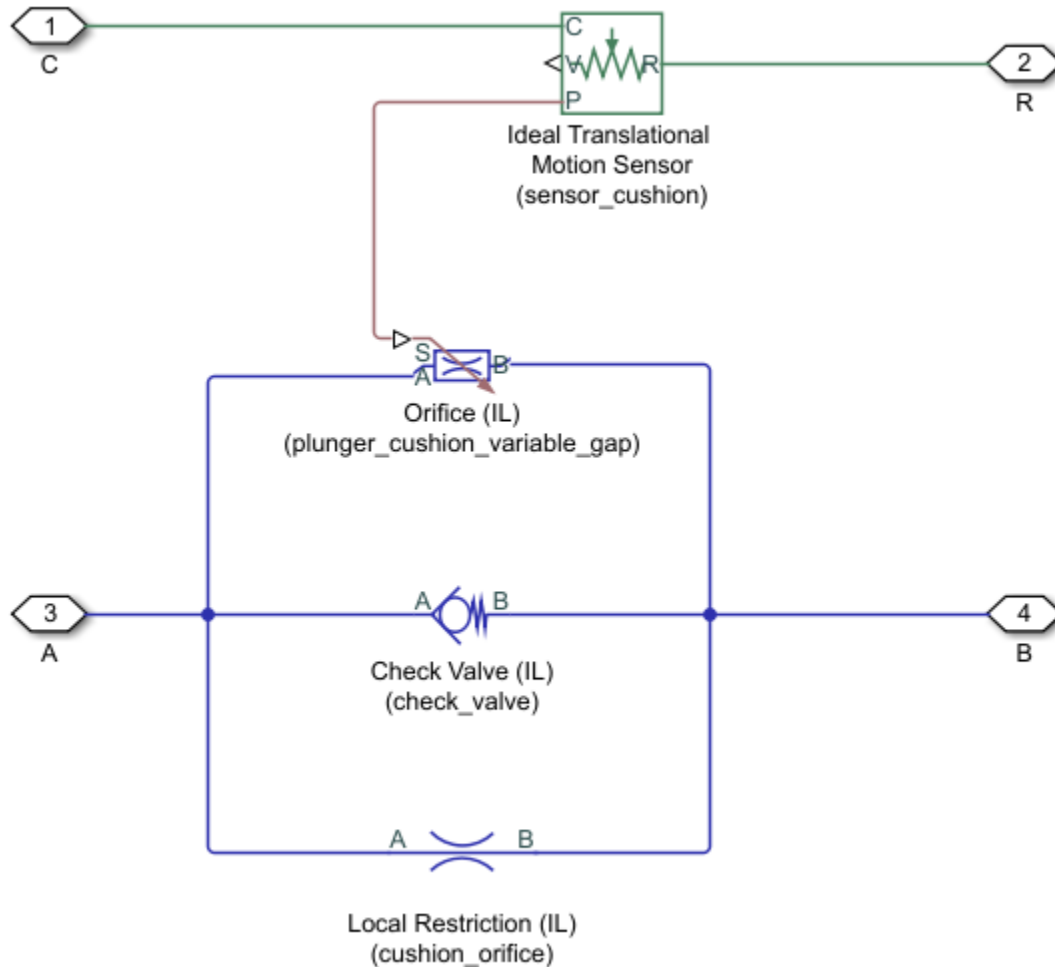
As the piston moves toward the cap (to the left in the figure), the plunger (the cushioning bush) enters the chamber in the cap and creates an additional resistance to the fluid leaving the cylinder chamber. The piston deceleration starts when the plunger enters the opening in the cap and closes the main fluid exit. In this state, the fluid flows through the gap between the cylinder and the cap through a cushioning valve. This restricts the flow rate leaving the cylinder chamber and reduces the initial speed of the piston.

The device contains a check valve between the cylinder and the cap. The check valve eases piston response during retraction by providing a flow path between the cap and cylinder chamber.

The cylinder cushion is a composite of a variable orifice, a fixed orifice, and a check valve. The variable orifice provides a variable opening between the plunger and end cap cavity. The fixed orifice connects the piston chamber to the cushion chamber. The check valve provides a flow path between the cushion chamber and the piston chamber during piston retraction only.

The Cylinder Cushion (IL) block is a composite component that consists of these blocks shown in the figure:

- A Local Restriction (IL) block that models the cushioning valve.
- A Check Valve (IL) block that models the check valve.
- An Orifice (IL) block that models the variable gap between the plunger and the end cap.
- An Ideal Translational Motion Sensor block that converts the separation between the plunger and the cavity in the end cap into a physical signal. This signal controls the opening of the Orifice (IL) block.



The Cylinder Cushion (IL) block is an actuator building block. A single-acting or double-acting actuator can optionally include cylinder cushions to slow piston motion near the ends of the stroke. This prevents extreme impacts when the piston is stopped by the end caps.

Ports **A** and **B** are isothermal liquid conserving ports associated with the chamber inlet and outlet, respectively. Port **R** is a mechanical translational conserving port connected with the piston plunger. Port **C** is a mechanical translational conserving port that corresponds to the cylinder clamping structure. The block develops a cushioning effect for the flow rate from port **B** to port **A**. The check valve in the block is oriented from port **A** to port **B**.

### Equation for Area of Variable Orifice

In the variable orifice, it is assumed that when the plunger is far away from the cushion, the orifice area is fully open and equal to  $\pi D_{plunger}^2/4$ , where  $D_{plunger}$  is the diameter of the circular plunger. Also, when the plunger is in the cushion, the orifice is fully closed and the orifice area is equal to the leakage area. As the plunger moves close to the cushion, the fluid flows radially from the cylinder chamber to the cap chamber through the gap between the plunger and the opening in the cap. Therefore, it can be assumed that the orifice area changes linearly with piston displacement between



the maximum area and the leakage area. The orifice area for a given position of the piston is calculated as:

$$S = \begin{cases} S_{leak}, & \varepsilon x_{piston} \leq L_{plunger} \\ S_{max}, & \varepsilon x_{piston} \geq L_{plunger} + \frac{D_{plunger}}{4} \\ \frac{S_{max} - S_{leak}}{\frac{D_{plunger}}{4}} (\varepsilon x_{piston} - L_{plunger}) + S_{leak}, & L_{plunger} < \varepsilon x_{piston} < L_{plunger} + \frac{D_{plunger}}{4} \end{cases}$$

where:

- $S$  is the orifice area for a given position of the piston.
- $S_{leak}$  is the **Leakage area**.
- $S_{plunger}$  is the **Cushion plunger cross-sectional area**.
- $S_{max}$  is the **Maximum orifice area**. It is equal to  $S_{plunger}$ .
- $x_{piston}$  is the displacement of the piston. (You must provide the initial displacement of the piston  $x_{0,piston}$  as a block parameter.)
- $\varepsilon$  is the **Actuator mechanical orientation** of the cylinder cushion (1 if the displacement indicates positive motion, -1 if the displacement moves in the negative direction).
- $L_{plunger}$  is the **Cushion plunger length**.
- $D_{plunger}$  is the **Cushion plunger diameter**.

### Numerically-Smoothed Area and Pressure

At the extremes of the orifice area and check valve pressure range, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to all calculated areas and valve pressures, but primarily influences the simulation at the extremes of these ranges.

The normalized orifice area is calculated as:

$$\widehat{S} = \frac{(S - S_{leak})}{(S_{max} - S_{leak})}.$$

The **Smoothing factor**,  $f$ , is applied to the normalized area:

$$\widehat{S}_{smoothed} = \frac{1}{2} + \frac{1}{2} \sqrt{\widehat{S}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2} \sqrt{(\widehat{S} - 1)^2 + \left(\frac{f}{4}\right)^2}.$$

The smoothed orifice area is:

$$S_{smoothed} = \widehat{S}_{smoothed}(S_{max} - S_{leak}) + S_{leak}.$$

Similarly, the normalized valve pressure is:

$$\widehat{p} = \frac{(p - p_{cracking})}{(p_{max} - p_{cracking})}.$$

where:

- $p_{cracking}$  is the **Check valve cracking pressure differential**.
- $p_{max}$  is the **Check valve maximum pressure differential**.

Smoothing applied to the normalized pressure is:

$$\widehat{p}_{smoothed} = \frac{1}{2} + \frac{1}{2}\sqrt{\widehat{p}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2}\sqrt{(\widehat{p} - 1)^2 + \left(\frac{f}{4}\right)^2},$$

and the smoothed pressure is:

$$p_{smoothed} = \widehat{p}_{smoothed}(p_{max} - p_{cracking}) + p_{cracking}.$$

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Entry port of the liquid to the cushion chamber.

#### B — Liquid port

isothermal liquid

Exit port of the liquid from the cushion chamber

#### R — Rod

mechanical translational

Mechanical translational conserving port connected with the piston plunger velocity and force.

#### C — Case

mechanical translational

Mechanical translational conserving port connected to the cylinder reference structure.

## Parameters

### Cushion Plunger

#### Cushion plunger cross-sectional area — Cross-sectional area of cushion plunger

1e-4 m<sup>2</sup> (default) | positive scalar

Area of the cross-section of the cushion plunger, which is assumed to be circular. The area is equal to  $\pi D_{plunger}^2/4$ , where  $D_{plunger}$  is the diameter of the circular plunger.

#### Cushion plunger length — Length of cushion plunger

1e-3 m (default) | positive scalar

Length of the cushion plunger.

#### Actuator piston initial displacement — Initial displacement of attached piston

0 m (default) | scalar

Displacement of the piston in the cylinder at the start of simulation. This displacement determines the initial area of the variable orifice that models the variable gap between the plunger and the end cap.

### Dependencies

If the **Actuator mechanical orientation** block parameter is set to Pressure at A causes positive displacement of R relative to C, the value of the piston initial displacement must be positive or zero.

If the **Actuator mechanical orientation** block parameter is set to Pressure at A causes negative displacement of R relative to C, the value of the piston initial displacement must be negative or zero.

### Actuator mechanical orientation – Piston displacement direction

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Piston displacement direction of the connected actuator block. If this parameter is set to Pressure at A causes positive displacement of R relative to C, the piston extends when **R - C** is positive. If this parameter is set to Pressure at A causes negative displacement of R relative to C, the piston retracts when **R - C** is positive.

### Valves

#### Cushion orifice area – Orifice area of cushioning valve

1e-6 m<sup>2</sup> (default) | positive scalar

Constant orifice area of the valve through which the fluid flows from the cylinder chamber to the cap chamber when the plunger is inside the opening in the cap.

#### Leakage area between plunger and cushion sleeve – Total leakage area when the plunger is inside the cap opening

1e-7 m<sup>2</sup> (default) | positive scalar

Total area of possible leaks when the plunger is inside the cap opening (the cushion sleeve). The area of the variable orifice modeling gap between the plunger and the cushion sleeve is equal to this leakage area when the displacement of the piston is less than or equal to the **Cushion plunger length** parameter.

#### Check valve cracking pressure differential – Pressure differential at which the check valve starts to open

0.01 MPa (default) | positive scalar

Minimum pressure differential across the check valve at which the valve starts to open. The check valve allows free flow of the liquid from the cushion chamber to the piston chamber but does not allow flow in the opposite direction.

#### Check valve maximum pressure differential – Pressure differential needed to fully open the check valve

0.1 MPa (default) | positive scalar

Pressure differential across the check valve needed to fully open the valve. The value of this parameter must be greater than the **Check valve cracking pressure differential** parameter. The

check valve allows free flow of the liquid from the cushion chamber to the piston chamber but does not allow flow in the opposite direction.

**Check valve maximum area — Opening area when check valve is fully open**

1e-4 m<sup>2</sup> (default) | positive scalar

Passage area of the check valve when the valve is fully open.

**Check valve leakage area — Total leakage area when check valve is fully closed**

1e-10 m<sup>2</sup> (default) | positive scalar

Total area of possible leaks when the check valve is fully closed.

**Smoothing factor — Amount of smoothing to apply to check valve and variable orifice opening area functions**

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

## Version History

Introduced in R2020a

## References

[1] Rohner, P. *Industrial Hydraulic Control*. Fourth edition. Brisbane: John Wiley & Sons, 1995.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Single-Acting Actuator (IL) | Double-Acting Actuator (IL) | Cylinder Friction (IL)

# Cylinder Friction

Friction in hydraulic cylinders

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Hydraulic Cylinders



## Description

The Cylinder Friction block simulates friction in the contact between moving bodies in hydraulic cylinders. Use this block as a building block in combination with double- and single-acting cylinders to develop a cylinder model with friction. The block simulates the friction force as a function of relative velocity and pressure, and assumes this force is the sum of the Stribeck, Coulomb, and viscous components. The Coulomb friction force consists of the preload force, which is caused by the seal squeeze during assembly, and the force proportional to the pressure. The sum of the Coulomb and Stribeck friction forces at zero velocity is the breakaway friction force. For more information, see the Translational Friction block reference page.

The block approximates the friction force as

$$F = F_C \cdot (1 + (K_{brk} - 1) \cdot \exp(-c_v |v|)) \text{sign}(v) + f_{vfr} \cdot v$$

$$F_C = F_{pr} + f_{cfr}(p_A + p_B)$$

where:

$F$	Friction force
$F_C$	Coulomb friction
$F_{pr}$	Preload force
$f_{cfr}$	Coulomb friction coefficient
$p_A, p_B$	Pressures in cylinder chambers
$K_{brk}$	Breakaway friction force increase coefficient
$c_v$	Transition coefficient
$v$	Relative velocity in the contact
$f_{vfr}$	Viscous friction coefficient

To avoid discontinuity at  $v = 0$ , the block introduces a small region,  $|v| \leq v_{th}$ , around zero velocity where the friction force is linearly proportional to velocity

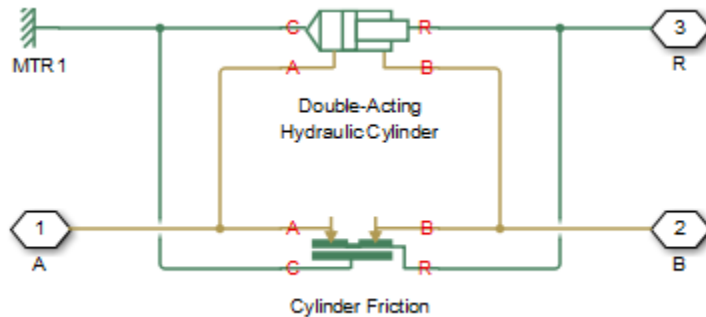
$$F = K \cdot v$$

$$K = \frac{F_C(1 + (K_{brk} - 1) \cdot \exp(-c_v v_{th})) + f_{vfr} \cdot v_{th}}{v_{th}}$$

where:

$K$	Proportionality coefficient
$v_{th}$	Velocity threshold

**R** and **C** are mechanical translational conserving ports associated with the rod and case, respectively. **A** and **B** are hydraulic conserving ports that you connect to ports **A** and **B** of the cylinder block, as shown in this illustration. The force generated by the block always opposes relative motion between the rod and the case.



## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Conserving

#### **A – Cylinder inlet**

hydraulic

Hydraulic conserving port connected to the cylinder inlet.

#### **B – Cylinder outlet**

hydraulic

Hydraulic conserving port connected to the cylinder outlet.

#### **R – Cylinder rod**

mechanical translational

Mechanical translational conserving port associated with the cylinder rod.

#### **C – Cylinder clamping structure**

mechanical translational

Mechanical translational conserving port associated with the cylinder clamping structure.

## Parameters

### **Preload force – Preload force caused by seal squeeze during assembly**

10 N (default) | nonnegative scalar

Preload force caused by the seal squeeze during assembly.

### **Coulomb friction force coefficient – Proportionality coefficient for Coulomb friction force**

1e-6 N/Pa (default) | nonnegative scalar

Coulomb friction coefficient. This value defines the proportionality between the Coulomb friction force and the pressure in cylinder chambers.

### **Breakaway friction increase coefficient – Friction force increase over Coulomb friction**

1 (default) | scalar greater than or equal to 1

Friction force increase over the Coulomb friction. The Coulomb friction force, multiplied by this coefficient, is breakaway friction force.

### **Viscous friction coefficient – Proportionality coefficient between viscous friction force and relative velocity**

100 N/(m/s) (default) | nonnegative scalar

Proportionality coefficient between the viscous friction force and the relative velocity.

### **Transition approximation coefficient – Approximation of transition between breakaway and Coulomb frictions**

10 s/m (default) | positive scalar

Value of the coefficient  $c_v$ , which the block uses for the approximation of the transition between the breakaway and the Coulomb frictions. Assign this value based on the following considerations: the Stribeck friction component reaches approximately 5% of its steady-state value at velocity  $3/c_v$ , and 2% at velocity  $4/c_v$ , which makes it possible to develop an approximate relationship  $c_v \approx 4/v_{\min}$ , where  $v_{\min}$  is the relative velocity at which friction force has its minimum value. The default value, 10 s/m, corresponds to a minimum friction at a velocity of about 0.4 m/s.

### **Linear region velocity threshold – Small vicinity near zero velocity where friction force is linearly proportional to relative velocity**

1e-4 m/s (default) | positive scalar

Small vicinity near zero velocity where the friction force is linearly proportional to the relative velocity. It is recommended that you use values in the range between 1e-6 and 1e-4 m/s.

## Version History

Introduced in R2006b

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Double-Acting Hydraulic Cylinder | Single-Acting Hydraulic Cylinder

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”



# Cylinder Friction (IL)

Adds friction to cylinders with moving components

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators / Auxiliary Components



## Description

The Cylinder Friction (IL) block models friction on a moving cylinder. The total friction is a combination of Stribeck, Coulomb, and viscous effects. The Coulomb friction component includes any initial force applied by the seal and the influence of pressure in the cylinder.

The Stribeck and viscous forces are calculated in the same way as for the Simscape Foundational Library Translational Friction block.

### The Stribeck Friction and Viscous Friction Forces

The Stribeck friction force is the dominating friction component at low velocities. It is calculated as:

$$F_{Stribeck} = \sqrt{2}e(R_{break, Coulomb} - 1) \cdot F_C \left( \frac{v}{v_{static, th}} \right) e^{-\left( \frac{v}{v_{static, th}} \right)^2},$$

where:

- $R_{break, Coulomb}$  is the ratio of the breakaway force to the Coulomb force:  $R_{Break, Coulomb} = \frac{F_{break}}{F_{Coulomb}}$ .
- $v$  is the velocity of the cylinder,  $v = v_R - v_C$ .
- $v_{static, th}$  is the threshold velocity for static torque:

$$v_{static, th} = \sqrt{2}v_{break},$$

where  $v_{break}$  is the **Breakaway friction velocity**. A transition range is established between 0 and the threshold velocity for static torque to ensure smooth modeling of the friction force.

- $F_C$  is introduced in "The Coulomb Friction Force" on page 1-675 section below.

The viscous friction force is based on the **Viscous friction coefficient** of the working fluid,  $f_{viscous}$ , and is proportional to the cylinder velocity:

$$F_{viscous} = f_{viscous}v.$$

### The Coulomb Friction Force

The Coulomb friction force is a force that acts normal to the friction surface. The cylinder motion creates a radial stress inside the fixed cylinder casing, which increases as the cylinder compresses the internal fluid. The radial stress is normal to the cylinder motion, and results in a Coulomb friction force that opposes cylinder motion.

The Coulomb frictional force is calculated as:

$$F_{Coulomb} = F_c \tanh\left(\frac{v}{v_{Coulomb,th}}\right),$$

where  $v$  is the relative velocity between ports **R** and **C** ( $v_R - v_C$ ), and  $v_{Coulomb,th}$  is the threshold velocity for Coulomb force:

$$v_{Coulomb,th} = \frac{v_{break}}{10}.$$

Note that the threshold velocity for Coulomb force is a different quantity than the threshold velocity for the static force, which is used to calculate the Stribeck friction force, although they both act as a threshold region to ensure smooth modeling of the Coulomb and Stribeck forces.

$F_C$  is the force contribution from seal preloading (the **Preload force**) and the pressure in the cylinder:

$$F_C = F_{preload} + f_{Coulomb}(P_A + P_B),$$

where  $f_{Coulomb}$  is the **Coulomb friction force coefficient**.  $P_A$  and  $P_B$ , the pressures at cylinder ports **A** and **B**, are gauge pressures with respect to the environmental pressure, specified either as atmospheric or another user-defined value in the **Environment pressure specification** parameter.

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry or exit point to the orifice.

#### B — Liquid port

isothermal liquid

Liquid entry or exit point to the orifice.

#### C — Mechanical port velocity, m/s

mechanical translational

Mechanical port for cylinder housing motion, in m/s.

#### R — Mechanical port velocity, m/s

mechanical translational

Mechanical port for cylinder rod motion, in m/s.

## Parameters

### Breakaway to Coulomb friction force ratio — Ratio of breakaway force to Coulomb friction force

1.2 (default) | positive scalar

Ratio of the breakaway force to the Coulomb friction force.

**Breakaway friction velocity – Threshold for motion against friction force**

0.1 m/s (default) | positive scalar

Threshold for movement against friction force.

**Preload force – Initial force in cylinder due to seal assembly**

20 N (default) | scalar

Initial force in the cylinder due to seal assembly.

**Coulomb friction force coefficient – Coulomb friction force coefficient**

1e-6 N/Pa (default) | positive scalar

Coulomb friction force coefficient.

**Viscous friction coefficient – Viscous friction coefficient**

100 N/(m/s) (default) | positive scalar

Viscous friction coefficient. This parameter is used to calculate the viscous friction force.

**Environment pressure specification – Pressure reference source**

Atmospheric pressure (default) | Specified pressure

Identifies pressure reference for the Coulomb friction calculation.

**Environment pressure – User-defined pressure reference**

0.101325 MPa (default) | positive scalar

User-defined pressure reference for the Coulomb friction calculation.

**Dependencies**To enable this parameter, set **Environment pressure specification** to Specified pressure.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Cylinder Cushion (IL) | Single-Acting Actuator (IL) | Pilot Valve Actuator (IL) | Double-Acting Actuator (IL)

# Hydraulic Double-Acting Valve Actuator

Double-acting hydraulic valve actuator

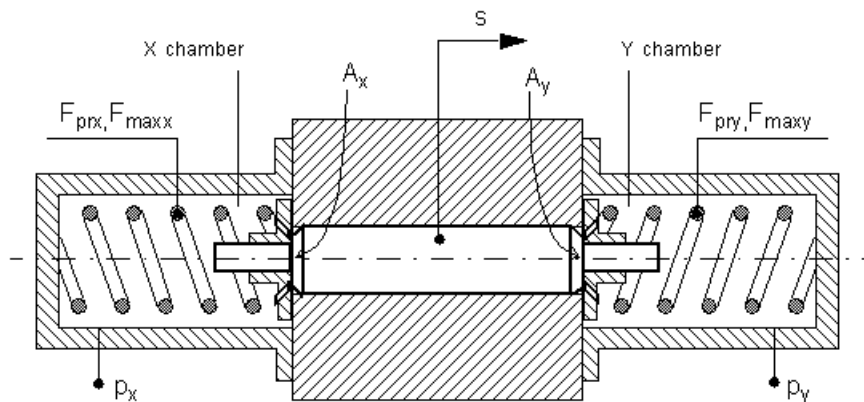


## Library

Valve Actuators

## Description

Use the Hydraulic Double-Acting Valve Actuator block as a pilot actuator for directional, pressure, or flow control valves in applications where all the forces, except spring force, and flow consumption can be neglected. The actuator consists of two single-acting actuators acting against each other. Each single-acting actuator consists of a piston, centering spring, and centering washer. When control pressure is applied to either hydraulic port, only one centering spring is compressed by its washer while the other butts against the valve body and exerts no force on the spool. When both control pressures are released, the springs force the washers against the valve body, and the spool centers between them. This design allows each actuator to have a different spring, preload force, and piston area.



As pressure applied to the piston develops enough force to overcome the spring preload, the piston moves to the opposite position until it reaches its maximum stroke. Pressure applied at port X shifts the valve in the  $x$ -direction, overcoming the spring located in the Y chamber. Pressure applied at port Y shifts the valve in the  $y$ -direction, overcoming the spring located in the X chamber.

The actuator is simulated according to the following equations:

$$F = p_x \cdot A_x - p_y \cdot A_y$$

$$L_x = \frac{str_x}{F_{maxx} - F_{prx}}$$

$$L_y = \frac{str_y}{F_{maxy} - F_{pry}}$$

If  $F \geq 0$ ,

$$s = \begin{cases} 0 & \text{for } F \leq F_{pry} \\ L_y \cdot (F - F_{pry}) \cdot or & \text{for } F_{pry} < F < F_{maxy} \\ str_y \cdot or & \text{for } F \geq F_{maxy} \end{cases}$$

If  $F < 0$ ,

$$s = \begin{cases} 0 & \text{for } |F| \leq F_{prx} \\ -L_x \cdot (|F| - F_{prx}) \cdot or & \text{for } F_{prx} < |F| < F_{maxx} \\ -str_x \cdot or & \text{for } |F| \geq F_{maxx} \end{cases}$$

where

$F$	Force acting on the valve
$s$	Piston displacement
$p_x$	Pressure in the actuator X chamber
$p_y$	Pressure in the actuator Y chamber
$A_x$	Valve face area in the X chamber
$A_y$	Valve face area in the Y chamber
$str_x$	Valve stroke in x-direction
$str_y$	Valve stroke in y-direction
$F_{prx}$	Chamber X spring preload force
$F_{maxx}$	Chamber X spring maximum force
$F_{pry}$	Chamber Y spring preload force
$F_{maxy}$	Chamber Y spring maximum force
$or$	Actuator orientation with respect to the globally assigned positive direction. If pressure applied at port X moves the piston in positive direction, $or$ equals 1. If pressure applied at port X moves the piston in negative direction, $or$ equals -1.

Connections X and Y are hydraulic conserving ports associated with the valve chambers. Connection P is a physical signal port whose output corresponds to piston displacement. Pressure applied at port X moves the piston in the positive or negative direction depending on the value of the **Actuator orientation** parameter.

## Basic Assumptions and Limitations

- The flow consumption associated with the valve motion is assumed to be negligible.
- The inertia, friction, and hydraulic axial forces are assumed to be small and are not taken into account.
- The clearances between the valve and the washers are not taken into account.

## Parameters

### Piston area at port X

Effective piston area at port X. The parameter value must be greater than zero. The default value is  $2e-4 \text{ m}^2$ .

### Piston area at port Y

Effective piston area at port Y. The parameter value must be greater than zero. The default value is  $2e-4 \text{ m}^2$ .

### Preload force at port X

Spring preload force at port X. The default value is 0.

### Preload force at port Y

Spring preload force at port Y. The default value is 0.

### Spring maximum force at port X

Chamber X spring maximum force. The parameter value must be greater than the spring preload force. The default value is 50 N.

### Spring maximum force at port Y

Chamber Y spring maximum force. The parameter value must be greater than the spring preload force. The default value is 50 N.

### Piston stroke at port X

Piston stroke in chamber X. The parameter value must be greater than or equal to zero. The default value is  $5e-3 \text{ m}$ .

### Piston stroke at port Y

Piston stroke in chamber Y. The parameter value must be greater than or equal to zero. The default value is  $5e-3 \text{ m}$ .

### Actuator orientation

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it moves the piston in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port X moves the piston in the negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

## Ports

The block has the following ports:

X

Hydraulic conserving port associated with the valve X chamber.

Y

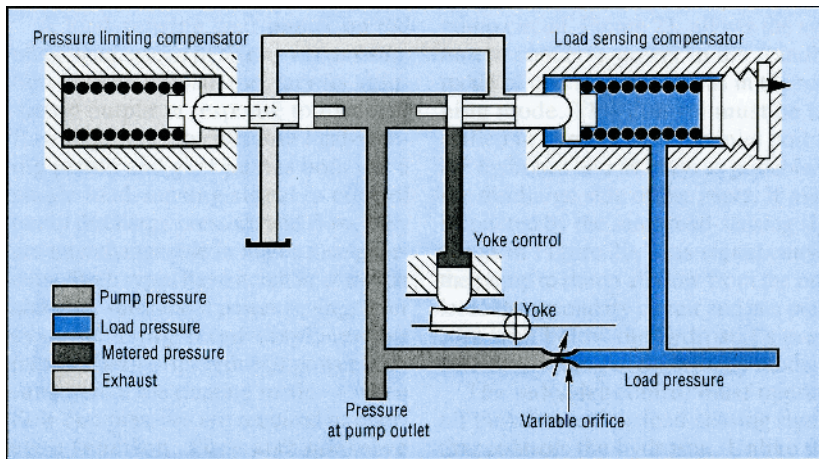
Hydraulic conserving port associated with the valve Y chamber.

P

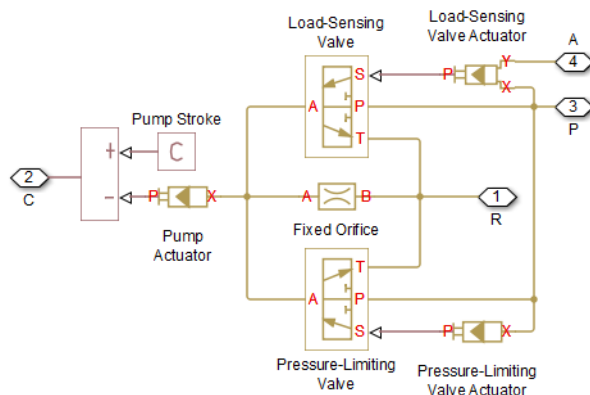
Physical signal port that outputs piston displacement.

## Examples

The following illustration shows a typical control unit of a variable-displacement pump that provides load sensing and pressure limiting (see [1] on page 1-682). In the unit, the load-sensing compensator varies the pump displacement to maintain a preset pressure differential across the variable orifice, while the pressure-limiting compensator does not allow the pump pressure to exceed the pressure limit.



The “Hydraulic Motor Driven by Load-Sensing Variable-Displacement Pump” example implements this type of control. The next illustration shows the schematic of the Control block in the example model.



There are three hydraulic valve actuators in the model:

- Pressure-Limiting Valve Actuator — A single-acting actuator that controls the Pressure-Limiting Valve.
- Pump Actuator — A single-acting valve actuator that acts on the pump displacement control device (yoke control).

- Load-Sensing Valve Actuator — A double-acting valve actuator that controls the Load-Sensing Valve. Its output is proportional to the difference between the pump pressure (port P) and the load pressure (port A).

Open the example model to see the parameter settings for the blocks.

## References

[1] F. Yeapple, *Fluid Power Design Handbook*, Marcel Dekker, Inc., 1995

## Version History

Introduced in R2007a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

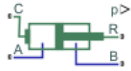
2-Position Valve Actuator | 3-Position Valve Actuator | Hydraulic Single-Acting Valve Actuator | Proportional and Servo-Valve Actuator



## Double-Acting Actuator (IL)

Linear conversion of pressure differential to actuation in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators



### Description

The Double-Acting Actuator (IL) block represents the linear conversion of a pressure differential between two chambers to piston motion. The piston actuation is controlled by the pressure differential acting on the piston plate that separates the chambers. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models. Fluid compressibility is optionally modeled in both piston chambers.

Ports **A** and **B** are isothermal liquid inlets. Port **C** represents the actuator casing, while piston velocity is returned at port **R**. When the piston position is calculated internally, it is reported at port **p**, and when the position is set by a connection to a Simscape Multibody™ joint, it is received as a physical signal at port **p**.

You can define the piston displacement direction with the **Mechanical orientation** parameter. If the mechanical orientation is set to **Pressure at A causes positive displacement of R relative to C**, the piston extends when the pressure differential  $p_A - p_B$  is positive. If **Mechanical orientation** is set to **Pressure at A causes negative displacement of R relative to C**, the piston retracts for a positive pressure difference between the liquid and gas chambers.

### Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber A volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

### Hard Stop Model

To avoid mechanical damage to an actuator when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Double-Acting Actuator (IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.
- Full stiffness and damping applied at bounds, damped rebound.

The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Piston stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

For more information about these settings, see the Translational Hard Stop block page.

### Cushion

You can optionally model cushioning toward the extremes of the piston stroke. Modeling cylinder end cushioning slows the piston motion as it approaches its maximum extension within its respective chamber, which is defined in **Piston stroke**. For more information on the functionality of a cylinder cushion, see Cylinder Cushion (IL).

### Friction

You can optionally model friction against piston motion. When **Cylinder friction effect** is set to On, the resulting friction is a combination of Stribeck, Coulomb, and viscous effects. The pressure difference is measured between the chamber pressure and the environment pressure. For more information on the friction model and its limitations, see the Cylinder Friction block.

### Leakage

You can optionally model leakage between the liquid chambers and the piston reservoir. When **Internal leakage** is set to On, Poiseuille flow is modeled between the piston and cylinder. This block uses the Simscape Foundation Library Laminar Leakage (IL) block. The flow rate is calculated as:

$$\dot{m} = \frac{\frac{\pi}{128} \left( d_0^4 - d_i^4 - \frac{(d_0^2 - d_i^2)^2}{\log(d_0/d_i)} \right)}{\nu L} (p_A - p_{env}),$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $L$  is the piston length,  $\mathbf{p} - P_0$ .
- $p_A$  is the pressure at port **A**.
- $p_{env}$  is the environmental pressure, which is selected in the **Environment pressure specification** parameter.

The cylinder diameter,  $d_0$ , is  $d_0 = d_i + 2c$ , where  $c$  is the **Piston-cylinder clearance**, and the piston diameter,  $d_i$ , is  $d_i = \sqrt{\frac{4A_P}{\pi}}$ , where  $A_P$  is the average of the **Piston cross-sectional area in chamber A** and **Piston cross-sectional area in chamber B** parameters.

### Numerically-Smoothed Area and Pressure

At the extremes of the cushion A and B orifice areas and check valve pressure ranges, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to all calculated areas and valve pressures, but primarily influences the simulation at the extremes of these ranges.

The normalized orifice area is calculated as:

$$\hat{A} = \frac{(A - A_{leak})}{(A_{max} - A_{leak})}.$$

where:

- $A_{leak}$  is the cushion A and cushion B **Leakage area between plunger and cushion sleeve**.
- $A_{max}$  is the cushion A and cushion B **Cushion plunger cross-sectional area**.

The **Smoothing factor**,  $f$ , is applied to the normalized area:

$$\widehat{A}_{smoothed} = \frac{1}{2} + \frac{1}{2}\sqrt{\widehat{A}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2}\sqrt{(\widehat{A} - 1)^2 + \left(\frac{f}{4}\right)^2}.$$

The smoothed orifice area is:

$$A_{smoothed} = \widehat{A}_{smoothed}(A_{max} - A_{leak}) + A_{leak}.$$

Similarly, the normalized valve pressure is:

$$\widehat{p} = \frac{(p - p_{cracking})}{(p_{max} - p_{cracking})}.$$

where:

- $p_{cracking}$  is the cushion **Check valve cracking pressure differential**.
- $p_{max}$  is the cushion **Check valve maximum pressure differential**.

Smoothing applied to the normalized pressure is:

$$\widehat{p}_{smoothed} = \frac{1}{2} + \frac{1}{2}\sqrt{\widehat{p}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2}\sqrt{(\widehat{p} - 1)^2 + \left(\frac{f}{4}\right)^2},$$

and the smoothed pressure is:

$$p_{smoothed} = \widehat{p}_{smoothed}(p_{max} - p_{cracking}) + p_{cracking}.$$

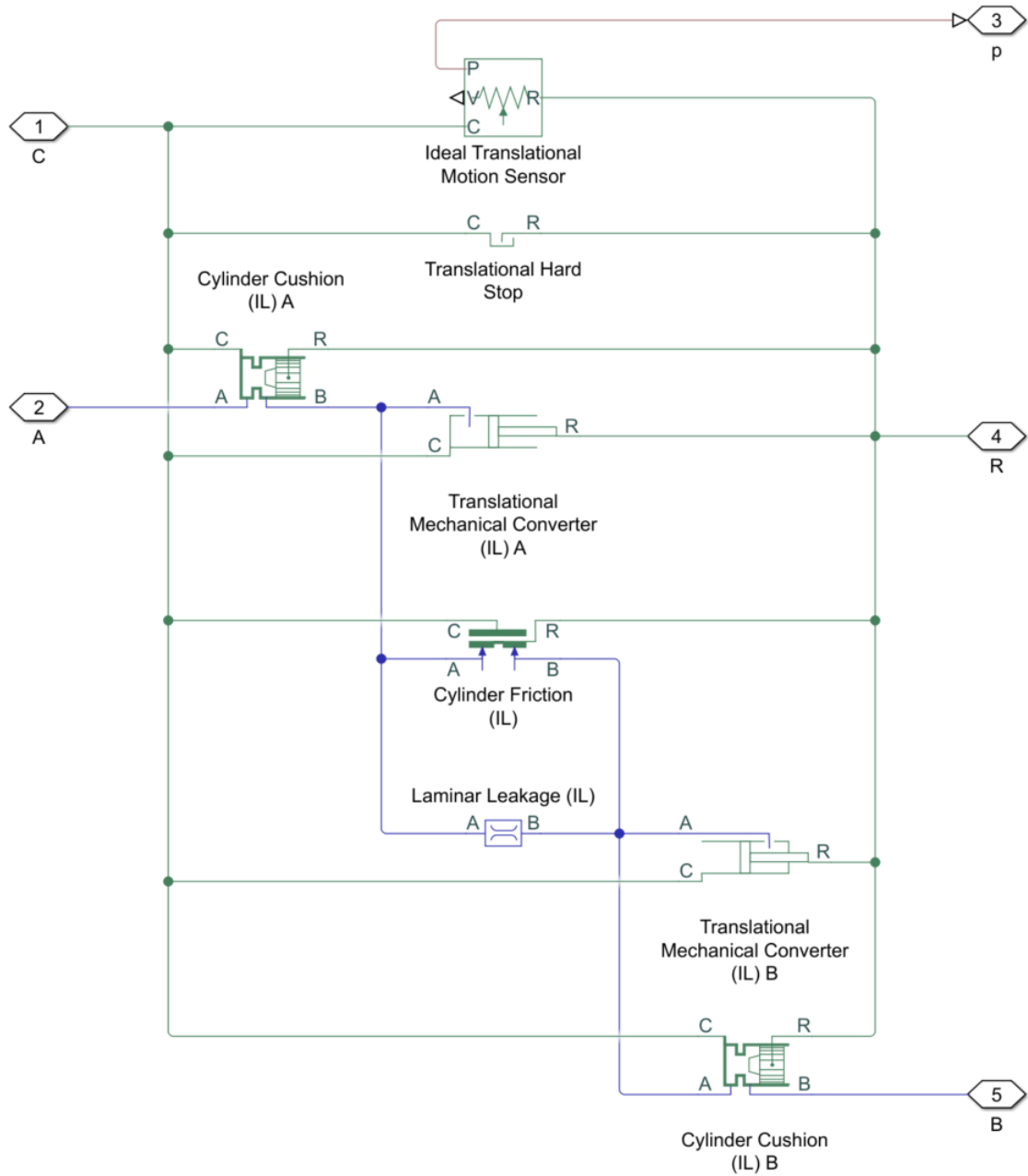
### Block Schematic

The Double-Acting Actuator (IL) block comprises four Simscape Foundation blocks:

- Laminar Leakage (IL)
- Translational Mechanical Converter (IL)
- Translational Hard Stop
- Ideal Translational Motion Sensor

and two Isothermal Liquid library blocks:

- Cylinder Cushion (IL)
- Cylinder Friction (IL)



**Momentum Balance**

The momentum conservation equation for the actuator is

$$F = \varepsilon(S_A p_A - S_B p_B - S_{Rod} p_{env})$$

where:

- $F$  is the force the liquid exerts on the converter interface. This force expression does not account for the force contributions due to the hard stop, cylinder cushions, or cylinder friction subcomponents. To see those force contributions to the converter interface, see the documentation pages for those subcomponents.
- $\varepsilon$  depends on the **Mechanical orientation** of the converter. If **Mechanical orientation** is Pressure at A causes positive displacement of R relative to C,  $\varepsilon = 1$ . If **Mechanical orientation** is Pressure at A causes negative displacement of R relative to C,  $\varepsilon = -1$ .
- $S_{Rod}$  is the rod cross-sectional area where  $S_{Rod} = S_A - S_B$ .
- $S_A$  is the value of the **Piston cross-sectional area in chamber A** parameter.
- $S_B$  is the value of the **Piston cross-sectional area in chamber B** parameter.
- $p_A$  is the pressure inside chamber A.
- $p_B$  is the pressure inside chamber B.
- $p_{env}$  is the environment pressure.

## Ports

### Input

#### **p — Piston position input, m**

physical signal

Physical signal input port associated with the piston position that you specify using a Simscape Multibody block.

#### **Dependencies**

To expose this port, set **Piston displacement from chamber A cap** to Provide input signal from Multibody joint.

### Output

#### **p — Piston position output, m**

physical signal

Physical signal port associated with the piston position.

#### **Dependencies**

To expose this port, set **Piston displacement from chamber A cap** to Calculate from velocity of port R relative to port C.

## Conserving

#### **A — Inlet to chamber A**

isothermal liquid

Isothermal liquid conserving port associated with the inlet to chamber A.

#### **B — Inlet to chamber B**

isothermal liquid

Isothermal liquid conserving port associated with the inlet to chamber B.

**C – Actuator casing**

mechanical translational

Mechanical translational conserving port associated with the case.

**R – Actuator piston**

mechanical translational

Mechanical translational conserving port associated with the piston.

**Parameters****Actuator****Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

**Piston cross-sectional area in chamber A – Chamber A piston area**0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod on the chamber A side.

**Piston cross-sectional area in chamber B – Chamber B piston area**0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod on the chamber B side.

**Piston stroke – Maximum piston travel distance**

0.1 m (default) | positive scalar

Maximum piston travel distance.

**Dead volume in chamber A – Chamber A fluid volume at full piston retraction**1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0 in chamber A. This is the liquid volume when the piston is up against the actuator end cap.

**Dead volume in chamber B – Chamber B fluid volume at full piston retraction**1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0 in chamber B. This is the liquid volume when the piston is up against the actuator end cap.

**Environment pressure specification — Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

**Environment pressure — User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Breakaway to Coulomb friction force ratio — Ratio of breakaway force to Coulomb friction force**

1.2 (default) | positive scalar

Ratio of the breakaway force to the Coulomb friction force.

**Dependencies**

To enable this parameter, in the **Friction** tab, set **Cylinder friction effect** to On.

**Breakaway friction velocity — Threshold for motion**

0.1 m/s (default) | positive scalar

Threshold velocity for motion against friction force to begin.

**Dependencies**

To enable this parameter, in the **Friction** tab, set **Cylinder friction effect** to On.

**Hard Stop****Hard stop stiffness coefficient — Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient. This value must be greater than 0.

**Hard stop damping coefficient — Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient.

**Hard stop model — Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

**Transition region — Application range of hard stop force model**

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of this range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

**Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

**Converter Cushion A****Cylinder A end cushioning – Whether to model piston slow-down at maximum extension**

Off (default) | On

Whether to model piston slow-down at maximum extension. See the Cylinder Cushion (IL) block for more information.

**Cushion plunger cross-sectional area – Cylinder cushion plunger area**

1e-4 m<sup>2</sup> (default) | positive scalar

Area of the plunger inside the actuator cushion element.

**Dependencies**

To enable this parameter, set **Cylinder A end cushioning** to On.

**Cushion plunger length – Length of cushion plunger**

1e-3 m (default) | positive scalar

Length of the cushion plunger.

**Dependencies**

To enable this parameter, set **Cylinder A end cushioning** to On.

**Cushion orifice area – Area of orifice between cushion chambers**

1e-6 m<sup>2</sup> (default) | positive scalar

Area of the orifice between cushion chambers.

**Dependencies**

To enable this parameter, set **Cylinder A end cushioning** to On.

**Leakage area between plunger and cushion sleeve – Gap between cushion plunger and sleeve**

1e-7 m<sup>2</sup> (default) | positive scalar

Gap area between the cushion plunger and sleeve. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Cylinder A end cushioning** to On.

**Check valve cracking pressure differential – Cushion threshold pressure**

0.01 MPa (default) | positive scalar



Pressure beyond which the valve operation is triggered. When the pressure difference between port **A** and  $P_{env}$  meets or exceeds the **Check valve cracking pressure differential**, the cushion valve begins to open.

#### Dependencies

To enable this parameter, set **Cylinder A end cushioning** to On.

**Check valve maximum pressure differential – Maximum cushion differential pressure**  
0.1 MPa (default) | positive scalar

Maximum cushion valve differential pressure. This parameter provides an upper limit to the pressure so that system pressures remain realistic.

#### Dependencies

To enable this parameter, set **Cylinder A end cushioning** to On.

**Check valve maximum area – Area of fully opened cushion valve**  
 $1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the cushion valve in its fully open position.

#### Dependencies

To enable this parameter, set **Cylinder A end cushioning** to On.

**Check valve leakage area – Cushion valve gap area when in fully closed position**  
 $1e-10 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the cushion check valve is in a fully closed position. Any area smaller than this value is saturated to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

#### Dependencies

To enable this parameter, set **Cylinder A end cushioning** to On.

### Converter Cushion B

**Cylinder B end cushioning – Whether to model piston slow-down at maximum extension**

Off (default) | On

Whether to model piston slow-down at maximum extension. See the Cylinder Cushion (IL) block for more information.

**Cushion plunger cross-sectional area – Cylinder cushion plunger area**  
 $1e-4 \text{ m}^2$  (default) | positive scalar

Area of the plunger inside the actuator cushion element.

#### Dependencies

To enable this parameter, set **Cylinder B end cushioning** to On.

**Cushion plunger length – Length of cushion plunger**  
 $1e-3 \text{ m}$  (default) | positive scalar

Length of the cushion plunger.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Cushion orifice area — Area of orifice between cushion chambers**

1e-6 m<sup>2</sup> (default) | positive scalar

Area of the orifice between cushion chambers.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Leakage area between plunger and cushion sleeve — Gap between cushion plunger and sleeve**

1e-7 m<sup>2</sup> (default) | positive scalar

Gap area between the cushion plunger and sleeve. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Check valve cracking pressure differential — Cushion threshold pressure**

0.01 MPa (default) | positive scalar

Pressure beyond which the valve operation is triggered. When the pressure difference between port **A** and  $P_{env}$  meets or exceeds the **Check valve cracking pressure differential**, the cushion valve begins to open.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Check valve maximum pressure differential — Maximum cushion differential pressure**

0.1 MPa (default) | positive scalar

Maximum cushion valve differential pressure. This parameter provides an upper limit to the pressure so that system pressures remain realistic.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Check valve maximum area — Area of fully opened cushion valve**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the cushion valve in its fully open position.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to 0n.

**Check valve leakage area — Cushion valve gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the cushion check valve is in a fully closed position. Any area smaller than this value is saturated to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to On.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the variable orifice and check valve are in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Cylinder B end cushioning** to On.

**Friction****Cylinder friction effect — Whether to model friction against piston motion**

Off (default) | On

Whether to model friction against piston motion. The model accounts for Coulomb, Stribeck, and viscous friction. See the Cylinder Friction block for more information.

**Preload force — Initial force on cylinder**

20 N (default) | scalar

Force on the cylinder when it is in the neutral position.

**Dependencies**

To enable this parameter, set **Cylinder friction effect** to On.

**Coulomb friction force coefficient — Coulomb friction force coefficient**

1e-6 N/Pa (default) | positive scalar

Coulomb force coefficient of friction.

**Dependencies**

To enable this parameter, set **Cylinder friction effect** to On.

**Viscous friction coefficient — Viscous friction coefficient**

100 N/(m/s) (default) | positive scalar

Viscous friction coefficient.

**Dependencies**

To enable this parameter, set **Cylinder friction effect** to On.

**Leakage****Internal leakage — Whether to model annular leakage**

Off (default) | On

Whether to model annular leakage between the fluid chamber and the piston reservoir at reference environment conditions. The leakage is considered laminar. See the Laminar Leakage (IL) block for more information.

**Piston-cylinder clearance — Radial clearance**

1e-4 m (default) | positive scalar

Radial distance between the piston rod and cylinder casing.

**Dependencies**

To enable this parameter, set **Internal leakage** to On.

**Piston head length — Annular length of piston mounting**

0.01 m (default) | positive scalar

Annular length of the piston mounting, not including the piston rod.

**Dependencies**

To enable this parameter, set **Internal leakage** to On.

**Initial Conditions****Piston displacement from chamber A cap — Method for determining piston position**

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the piston position. The block can receive the position from a Multibody block when set to Provide input signal from Multibody joint, or calculates the position internally and reports the position at port **p**. The position is between 0 and the **Piston stroke** when the mechanical orientation is positive and 0 and **-Piston stroke** when the mechanical orientation is negative.

**Initial piston displacement from chamber A cap — Piston position measured from chamber A cap at start of simulation**

0 m (default) | scalar

Piston position with respect to the chamber A cap at the start of the simulation.

**Dependencies**

To enable this parameter, set **Piston displacement from chamber A cap** to Calculate from velocity of port R relative to port C.

**Fluid dynamic compressibility — Whether to model fluid compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

**Initial liquid pressure in chamber A — Starting liquid pressure in chamber A**

0.101325 MPa (default) | positive scalar

Starting liquid pressure for compressible fluids.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

### Initial liquid pressure in chamber B — Starting liquid pressure in chamber B

0.101325 MPa (default) | positive scalar

Starting liquid pressure for compressible fluids.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Single-Acting Actuator (IL) | Double-Acting Actuator (G-IL) | Double-Acting Rotary Actuator (IL) | Double-Acting Servo Valve Actuator (IL)

## Topics

“Connecting Simscape Networks to Simscape Multibody Joints”

## Double-Acting Actuator (TL)

Linear actuator with piston motion controlled by two opposing thermal liquid chambers

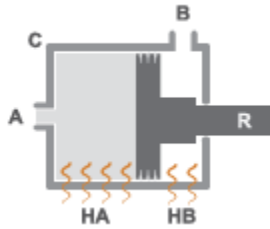
**Library:** Simscape / Fluids / Thermal Liquid / Actuators



### Description

The Double-Acting Actuator (TL) block represents a linear actuator with piston motion controlled by two opposing thermal liquid chambers. The actuator generates force in the extension and retraction strokes. The force generated depends on the pressure difference between the two chambers.

The figure shows the key components of the actuator model. Ports **A** and **B** represent the thermal liquid chamber inlets. Port **R** represents the translating actuator piston and port **C** the actuator case. Ports **HA** and **HB** represent the thermal interfaces between each chamber and the environment. The moving piston is adiabatic.



### Double-Acting Actuator Schematic

#### Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is considered neutral, or  $\theta$ , when the chamber A volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

The direction of the piston motion depends on the mechanical orientation setting in the block dialog box. If the mechanical orientation is positive, then a higher pressure at port **A** yields a positive piston translation relative to the actuator case. The direction of motion reverses for a negative mechanical orientation.

#### Hard Stop

A set of hard stops limit the piston range of motion. The hard stops are treated as spring-damper systems. The spring stiffness coefficient controls the restorative component of the hard-stop contact force and the damping coefficient the dissipative component.

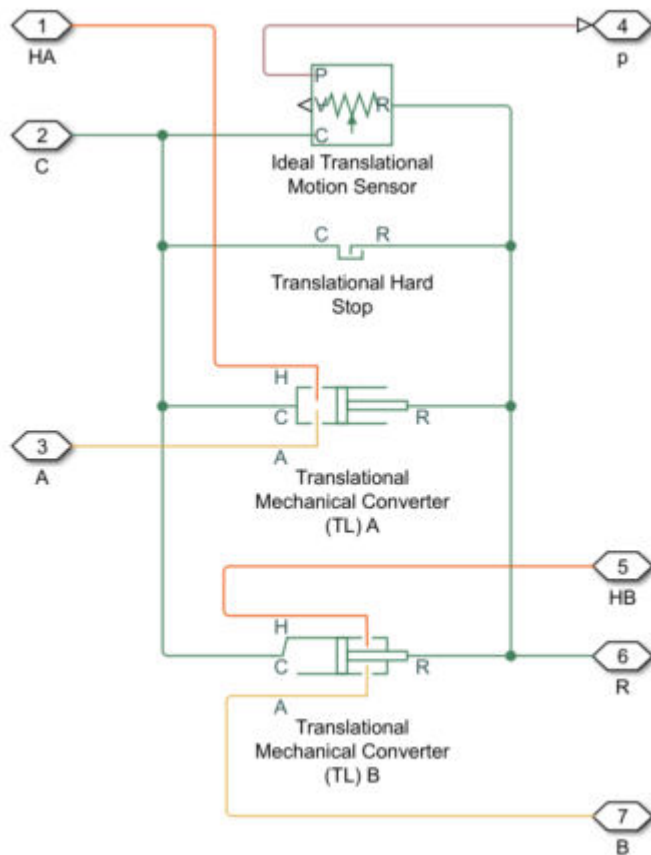
The hard stops are located at the distal ends of the piston stroke. If the mechanical orientation is positive, then the lower hard stop is at  $x = 0$  and the upper hard stop at  $x = +stroke$ . If the

mechanical orientation is negative, then the lower hard stop is at  $x = -stroke$  and the upper hard stop at  $x = 0$ .

### Block Composite

This block is a composite component based on the Simscape Foundation blocks:

- Translational Mechanical Converter (TL)
- Translational Hard Stop
- Ideal Translational Motion Sensor



### Composite Component Diagram

### Ports

#### Input

**p** – Piston position input, m

physical signal

Physical signal input port associated with the piston position that you specify using a Simscape Multibody block.

**Dependencies**

To expose this port, set **Piston displacement from chamber A cap** to Provide input signal from Multibody joint.

**Output****p – Piston position output, m**

physical signal

Physical signal port associated with the piston position.

**Dependencies**

To expose this port, set **Piston displacement from chamber A cap** to Calculate from velocity of port R relative to port C.

**Conserving****A – Chamber A inlet**

thermal liquid

Thermal liquid conserving port associated with the inlet to chamber A.

**B – Chamber B inlet**

thermal liquid

Thermal liquid conserving port associated with the inlet to chamber B.

**R – Actuator piston**

mechanical translational

Mechanical translational conserving port representing the actuator piston.

**C – Actuator casing**

mechanical translational

Mechanical translational conserving port representing the actuator casing.

**HA – Chamber A heat flow**

thermal

Thermal conserving port associated chamber A.

**HB – Chamber B heat flow**

thermal

Thermal conserving port associated with chamber B.

**Parameters****Actuator****Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C



Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

#### **Piston cross-sectional area in chamber A – Chamber A piston area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod on the chamber A side.

#### **Piston cross-sectional area in chamber B – Chamber B piston area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod on the chamber B side.

#### **Piston stroke – Maximum piston travel distance**

0.1 m (default) | positive scalar

Maximum piston travel distance.

#### **Dead volume in chamber A – Chamber A fluid volume at full piston retraction**

1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0 in chamber A. This is the liquid volume when the piston is up against the actuator end cap.

#### **Dead volume in chamber B – Chamber B fluid volume at full piston retraction**

1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0 in chamber B. This is the liquid volume when the piston is up against the actuator end cap.

#### **Environment pressure specification – Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

#### **Environment pressure – User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

#### **Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

#### **Hard Stop**

#### **Hard stop stiffness coefficient – Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient. This value must be greater than 0.

**Hard stop damping coefficient – Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient.

**Hard stop model – Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

**Transition region – Application range of hard stop force model**

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of this range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

**Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Double-Acting Actuator (TL-G) | Single-Acting Actuator (TL) | Double-Acting Actuator (IL)

**Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”

## Double-Acting Actuator (H-G)

(Not recommended) Linear actuator with opposing isothermal liquid and gas chambers

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**Note** This block has been renamed in Simscape Fluids 3.0 (release 2020a). In Release 2019b and older, this block was named Double-Acting Actuator (IL-G). Older models opened in R2020a currently work with the former version of this block.

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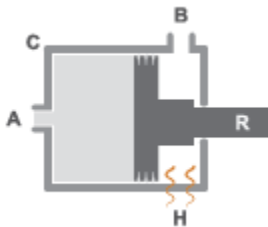
**Library:** Simscape / Fluids / Fluid Network Interfaces / Actuators



### Description

The Double-Acting Actuator (H-G) block represents a linear actuator with opposing chambers of isothermal liquid and gas. The chambers can be individually pressurized to power the actuator in both the extension and retraction strokes. A piston between the chambers converts the pressure difference across them into actuation force.

The figure maps the conserving ports of the block to the actuator parts. Ports **A** and **B** are the inlets of the isothermal liquid and gas chambers. Ports **R** and **C** are the translating piston and case. The gas chamber can exchange heat with the environment and is fitted for this purpose with port **H**. The isothermal liquid, being of constant temperature, exchanges heat neither with the environment nor with the gas across the piston.



The sign of the piston displacement relative to the case depends on the mechanical orientation of the actuator. Use the **Mechanical orientation** parameter to specify this setting. If the mechanical orientation is positive, the piston displacement is positive when the pressure is highest in the isothermal liquid chamber (port **A**). If the mechanical orientation is negative, the piston displacement (under the same pressure conditions) is negative.

Use port **P** to output the instantaneous piston position. The position measurement can be absolute or relative. Configure the **Piston position display** parameter to switch the measurement type if needed:

- From piston initial distance from port A — The measurement is absolute. The first reading is the value specified in the **Piston initial distance from port A**. If that value is 10 in, the first reading is also 10 in.

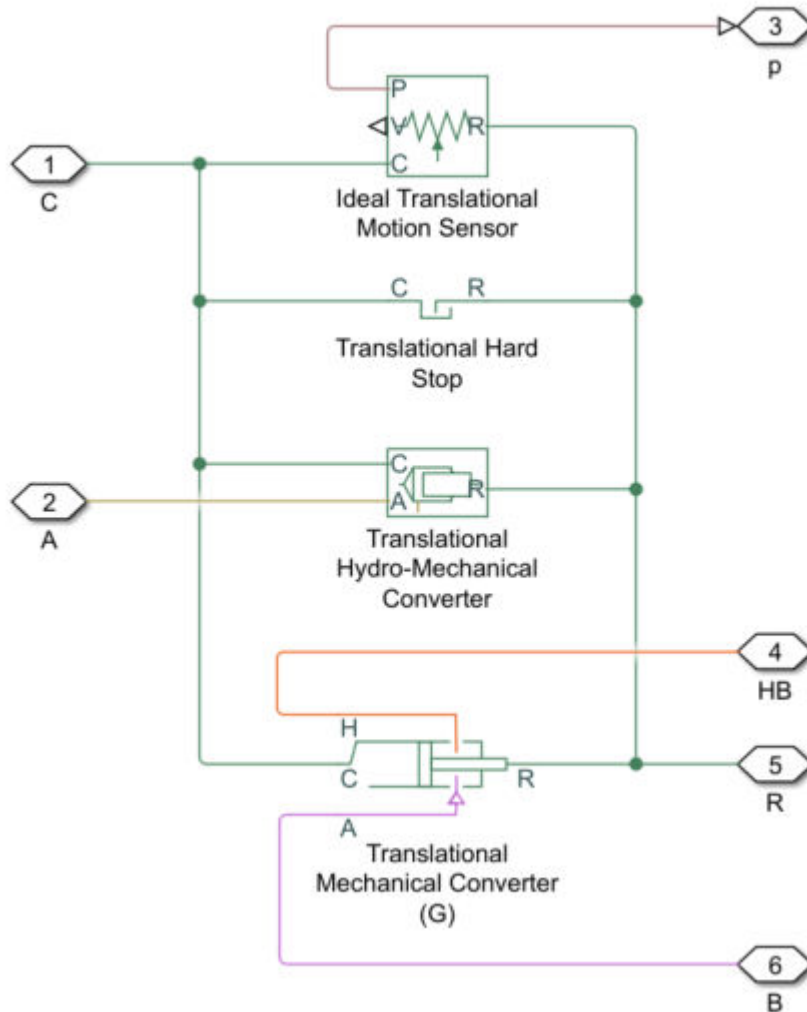
- **From zero** — The measurement is relative to the initial piston position. The first reading, as it corresponds to the initial piston position, is zero.

Hard stops limit the motion of the piston to the length of the case. The stops are modeled as spring-dampers, with spring and damping coefficients to capture material compliance. One is located at the bottom of the piston stroke and the other at the top:

- If the **Mechanical orientation** setting is **Positive**, the bottom stop is at zero, and the top stop is at a distance equal to the piston stroke.
- If the **Mechanical orientation** setting is **Negative**, the top stop is at zero, and the bottom stop is at a distance equal to the piston stroke.

The block is a composite component built from Simscape Foundation blocks. For more information on how the Double-Acting Actuator (H-G) block works, see the reference pages of the constituent blocks:

- Translational Hydro-Mechanical Converter
- Translational Mechanical Converter (G)
- Translational Hard Stop
- Ideal Translational Motion Sensor



## Ports

### Output

#### P – Piston position, m

physical signal

Piston position measurement. The measurement can be absolute or relative to the initial piston position. Use the **Piston position display** parameter to specify the measurement type.

### Conserving

#### A – Inlet to chamber A

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port associated with the inlet to chamber A.

**B — Inlet to chamber B**

gas

Gas conserving port associated with the inlet to chamber B.

**R — Actuator piston rod**

mechanical translational

Mechanical translational conserving port representing the piston rod. The piston is capable of translational motion relative to the casing.

**C — Actuator casing**

mechanical translational

Mechanical translational conserving port associated with the case.

**H — Gas chamber thermal surface**

thermal

Thermal conserving port associated with the surface of the gas chamber through which heat exchange with the surroundings can occur. The thermal processes at this port determine the temperature in the gas chamber and therefore at port **B**.

**Parameters****Hydraulic Side****Mechanical orientation — Direction of motion of the piston relative to the direction of flow of the fluid**

Positive | Negative

Orientation of the actuator piston relative to the direction of fluid flow. A positive orientation causes the piston to move in the positive direction relative to the actuator casing in response to a positive flow rate through port A. The mechanical orientation affects the placement of the piston hard stops. See the block description for more information on the hard stop placement.

**Piston cross-sectional area in chamber A — Cross-sectional area of the fluid volume in the hydraulic chamber**0.01 m<sup>2</sup> (default) | scalar

Area normal to the direction of flow in the body of the hydraulic chamber. The block uses this area to calculate the hydraulic force due to the fluid pressure in the hydraulic chamber. This parameter must be greater than zero.

**Piston stroke — Distance of travel of piston from hard stop to hard stop**

0.1 m (default) | scalar

Total distance of travel available to the piston, from one hard stop to the other. The hard stops limit the piston motion so that the piston is confined to stroke of the piston. See the block description for more information on the locations of the hard stops.

**Piston position display — Reference against which to output piston position**

From piston initial distance from port A (default) | From zero

Reference against which to measure the piston position. This setting reflects in the output of port **P**. Use the default setting, *From piston initial distance from port A*, to output the absolute piston position; the first position reading is then the value of the **Piston initial distance from port A** parameter. Use the alternative setting, *From zero*, to output the piston position relative to the specified initial value; the first position reading is then zero.

**Piston initial distance from port A — Piston position relative to the hydraulic chamber inlet at the start of simulation**

0 m (default) | scalar

Distance of the piston from the hard stop closest to the hydraulic inlet at the start of simulation. Use this parameter to change the starting position of the piston. This parameter affects the placement of the piston hard stops. For more information on the hard stop placement, see the block description.

**Fluid dynamic compressibility — Choice to model the effects of dynamic compressibility inside the hydraulic chamber**

Off (default) | On

Option to model the effects of dynamic compressibility inside the hydraulic chamber. The hydraulic fluid is treated as compressible if this parameter is set to *On* and as incompressible if it is set to *Off*. The block ignores the dependence of the hydraulic fluid density on pressure and temperature if *Off* is selected.

**Dead volume in chamber A — Fluid volume in the hydraulic chamber in the bottomed-out position**

$1e-4 \text{ m}^3$  (default) | scalar

Hydraulic fluid volume remaining in the hydraulic chamber when the piston is pressed against the hard stop closest to the hydraulic inlet. The dead volume enables the block to capture the internal states of the hydraulic fluid volume—its pressure and temperature—when this volume is at a minimum. This parameter must be greater than zero.

**Dependencies**

This parameter is enabled when the **Compressibility** parameter is set to *On*.

**Specific heat ratio — Specific heat ratio of the gas entrained in the hydraulic fluid**

1.4 (default) | scalar

Ratio of the specific heat of the gas entrained in the hydraulic fluid at constant pressure to that at constant volume. The block uses this parameter in the calculations of density for the hydraulic fluid.

**Dependencies**

This parameter is enabled when the **Compressibility** parameter is set to *On*.

**Initial liquid pressure (gauge) — Gauge pressure in the hydraulic chamber relative to the actuator environment**

0 Pa (default) | scalar

Pressure inside the hydraulic chamber at simulation time zero relative to absolute zero. This parameter helps set the initial states of the hydraulic fluid volume.

**Dependencies**

This parameter is enabled when the **Compressibility** parameter is set to *On*.

## Gas Side

### **Piston cross-sectional area in chamber B — Cross-sectional area of the fluid volume in the gas chamber**

1e-3 m<sup>2</sup> (default) | positive scalar

Area normal to the direction of flow in the body of the gas chamber. The block uses this area to calculate the pneumatic force due to the fluid pressure in the gas chamber. This parameter must be greater than zero.

### **Cross-sectional area at port B — Cross-sectional area of the inlet of the gas chamber**

1e-3 m<sup>2</sup> (default) | positive scalar

Area normal to the direction of flow at the entrance to the gas chamber. The cross-sectional area at the entrance can differ from that in the body of the chamber. Set the two cross-sectional areas to different values to model the effects of a sudden area change at the inlet. This parameter must be greater than zero.

### **Dead volume in chamber B — Fluid volume in the gas chamber in the bottomed-out position**

1e-4 m<sup>3</sup> (default) | positive scalar

Gas volume remaining in the gas chamber when the piston is pressed against the hard stop closest to the gas inlet. The dead volume enables the block to capture the internal states of the gas volume—its pressure and temperature—when this volume is at a minimum. This parameter must be greater than zero.

### **Initial gas pressure (absolute) — Absolute pressure inside the gas chamber at the start of simulation**

0.101325 MPa (default) | scalar

Pressure inside the gas chamber at simulation time zero relative to absolute zero. This parameter helps set the initial state of the gas volume.

### **Environment pressure specification — Choice of atmospheric or custom environment pressure for the gas side**

Atmospheric pressure (default) | Specified pressure

Option to set the environment pressure of the gas chamber to the typical value of one earth atmosphere or to a custom value. Selecting **Specified pressure** exposes an additional parameter, **Environment pressure**, that you use to specify a custom pressure.

### **Environment pressure — Absolute pressure of the environment outside the gas chamber**

0.101325 MPa (default) | scalar

Pressure outside the gas chamber relative to absolute zero. This pressure acts against the pressure inside the gas chamber. A pressure of zero corresponds to a perfect vacuum.

## Dependencies

This parameter is enabled when the **Environment pressure specification** is set to **Specified pressure**.



## Hard Stop

### Hard-stop stiffness coefficient — Stiffness coefficient for the restorative portion of the hard-stop contact force

1e6 N/m (default) | scalar

Spring coefficient for use in the spring-damper model of the piston hard-stops. The spring force is assumed to be the same at both hard stops. Increase the coefficient value to model harder contact.

### Hard-stop damping coefficient — Damping coefficient for the dissipative portion of the hard-stop contact force

150 N/(m/s) (default) | scalar

Damping coefficient for use in the spring-damper model of the piston hard stops. The damping force is assumed to be the same at both hard stops. Increase the coefficient value to reduce piston bounce on contact.

### Hard stop model — Modeling approach for hard stops

Stiffness and damping applied smoothly through transition region (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Modeling approach for hard stops. Options include:

- Stiffness and damping applied smoothly through transition region — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- Full stiffness and damping applied at bounds, undamped rebound — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- Full stiffness and damping applied at bounds, damped rebound — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied. This is the hard-stop model used in previous releases.

### Transition region — Distance below which scaling is applied to the hard-stop force

0.1 mm (default) | scalar

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value specified here. It is at its full value when the distance to the hard stop is zero.

## Version History

Introduced in R2016b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

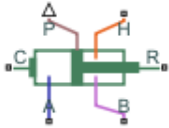
**See Also**

Double-Acting Actuator (G-IL) | Double-Acting Actuator (TL-G) | Double-Acting Actuator (TL) | Double-Acting Hydraulic Cylinder | Double-Acting Hydraulic Cylinder (Simple)

# Double-Acting Actuator (G-IL)

Linear actuator with isothermal liquid and gas chambers

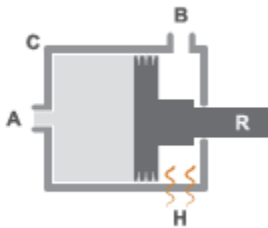
**Library:** Simscape / Fluids / Fluid Network Interfaces / Actuators



## Description

The Double-Acting Actuator (G-IL) block represents an isothermal liquid chamber and a gas chamber separated by a piston plate. The piston actuation is controlled by the pressure differential between the chambers. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models.

Port **A** is the isothermal liquid inlet and port **B** is the gas inlet. Connect elements for heat transfer between the gas chamber and the environment to port **H**. Port **C** acts as a mechanical translational reference for the actuator casing. Port **R** is associated with the actuator piston. The piston position is reported at port **P**.



## Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

## Hard Stop Model

To avoid mechanical damage to the piston when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Double-Acting Actuator (G-IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.

- Full stiffness and damping applied at bounds, damped rebound.

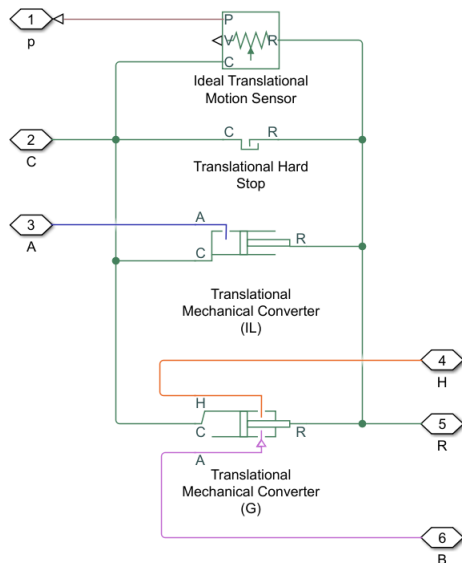
The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Piston stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

For more information about these settings, see the Translational Hard Stop block page.

### Block Schematic

The Double-Acting Actuator (G-IL) block is a composite of four Simscape Foundation blocks:

- Translational Mechanical Converter (G)
- Translational Mechanical Converter (IL)
- Translational Hard Stop
- Ideal Translational Motion Sensor



### Ports

#### Output

##### **p** – Piston position, m

physical signal

Physical signal port associated with the piston position.

#### Conserving

##### **A** – Inlet to chamber A

isothermal liquid

Isothermal liquid conserving port associated with the inlet to chamber A.

**B – Inlet to chamber B**

gas

Gas conserving port associated with the inlet to chamber B.

**C – Actuator casing**

mechanical translational

Mechanical translational conserving port associated with the case.

**R – Actuator piston rod**

mechanical translational

Mechanical translational conserving port associated with the piston rod.

**H – Heat flow**

thermal

Thermal conserving port associated with heat transfer to or from the gas chamber.

**Parameters****Configuration****Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Piston displacement direction. Pressure at A causes positive displacement of R relative to C corresponds to piston extension when the pressure difference between chambers A and B is positive. Pressure at A causes negative displacement of R relative to C corresponds to piston retraction when the pressure difference between chambers A and B is positive.

**Piston stroke – Maximum piston travel distance**

0.1 m (default) | positive scalar

Maximum piston travel distance.

**Initial piston displacement from chamber A cap – Piston position at start of simulation**

0 m (default) | scalar

Piston position at the start of the simulation.

**Hard-stop stiffness coefficient – Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient.

**Hard-stop damping coefficient – Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient for motion near the piston ends.

**Hard stop model – Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

**Transition region – Application range of hard stop force model**

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of the range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

**Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

**Isothermal Liquid Side****Piston cross-sectional area in chamber A – Cross-sectional area of piston rod**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod in chamber A.

**Dead volume in chamber A – Chamber volume at full piston retraction**

1e-5 m<sup>3</sup> (default) | positive scalar

Open volume in the fluid chamber when the piston is fully retracted.

**Fluid dynamic compressibility – Whether to model fluid compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

**Initial liquid pressure in chamber A – Initial liquid pressure for compressible fluids**

0.101325 MPa (default) | positive scalar

Initial liquid pressure for compressible fluids.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On.

**Environment pressure specification – Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

**Environment pressure – User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

#### Dependencies

To enable this parameter, set **Environment pressure specification** to Specified pressure.

#### Gas Side

##### **Piston cross-sectional area in chamber B – Cross-sectional area of piston rod**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod in chamber B.

##### **Cross-sectional area at port B – Port cross-sectional area**

1e-3 m<sup>2</sup> (default) | positive scalar

Cross-sectional area at port B.

##### **Dead volume in chamber B – Chamber volume at full piston retraction**

1e-5 m<sup>3</sup> (default) | positive scalar

Open volume in the gas chamber when the piston is fully retracted.

##### **Initial gas pressure in chamber B – Starting gas chamber pressure**

0.101325 MPa (default) | positive scalar

Initial pressure in the gas chamber.

##### **Initial gas temperature in chamber B – Starting gas chamber temperature**

293.15 K (default) | positive scalar

Initial temperature in the gas chamber.

##### **Environment pressure specification – Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

##### **Environment pressure – User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

#### Dependencies

To enable this parameter, set **Environment pressure specification** to Specified pressure.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

Double-Acting Actuator (IL) | Double-Acting Actuator (TL-G) | Double-Acting Rotary Actuator (IL) | Double-Acting Servo Valve Actuator (IL)

**Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”



## Double-Acting Actuator (TL-G)

Linear actuator with opposing thermal liquid and gas chambers

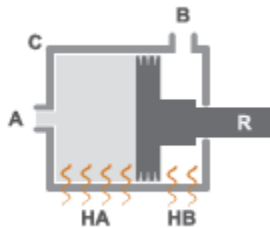
**Library:** Simscape / Fluids / Fluid Network Interfaces / Actuators



### Description

The Double-Acting Actuator (TL-G) block models a linear actuator with opposing chambers of thermal liquid and gas. The chambers can be individually pressurized to power the actuator in both extension and retraction strokes. A piston between the chambers converts the pressure difference across them into actuation force.

The figure maps the conserving ports of the block to the actuator parts. Ports **A** and **B** are the inlets of the thermal liquid and gas chambers. Ports **R** and **C** are the translating piston and case. The chambers can exchange heat with the environment and are fitted for this purpose with ports **HA** and **HB**. The piston is perfectly insulating. The thermal liquid and gas chambers do not exchange heat with each other.



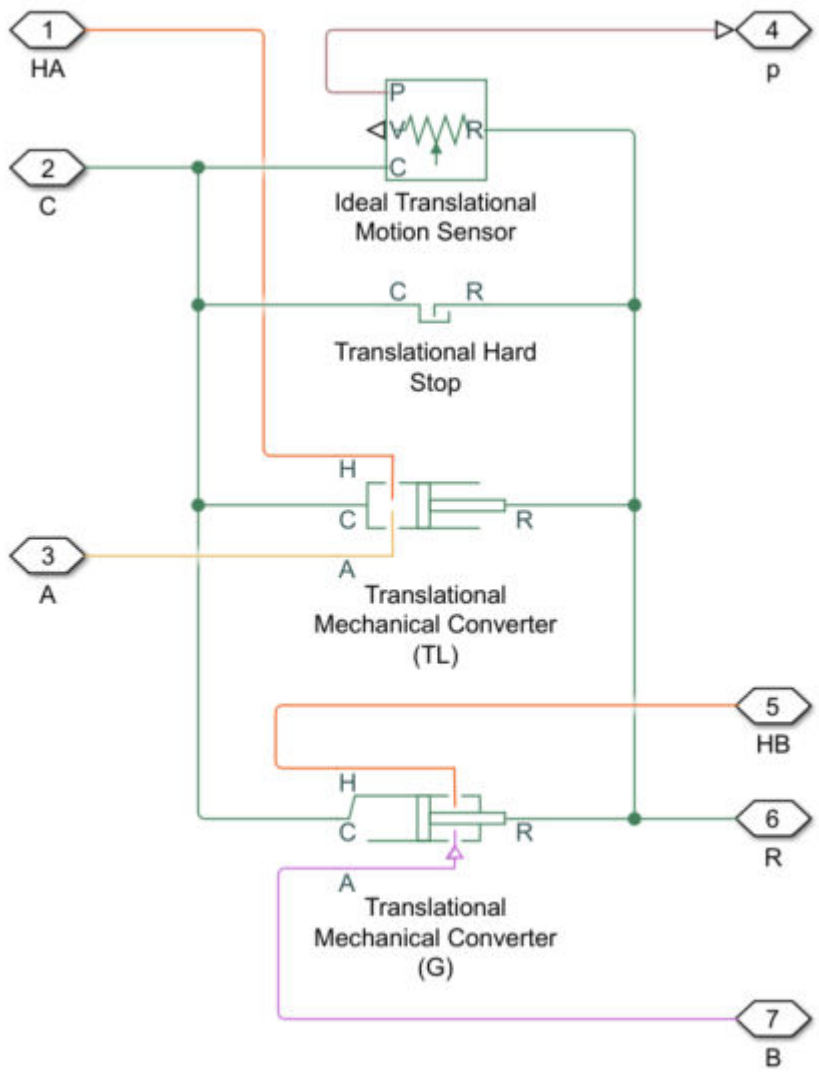
The sign of the piston displacement relative to the case depends on the mechanical orientation of the actuator. Use the **Mechanical orientation** parameter to specify this setting. If the mechanical orientation is positive, the piston displacement is positive when the pressure is highest in the thermal liquid chamber (port **A**). If the mechanical orientation is negative, the piston displacement (under the same pressure conditions) is negative.

Use port **P** to output the instantaneous piston position. The measurement is absolute (relative to zero). Hard stops limit the motion of the piston to the length of the case. The stops are modeled as spring-dampers, with spring and damping coefficients to capture material compliance. One is located at the bottom of the piston stroke and the other at the top:

- If the **Mechanical orientation** setting is **Positive**, the bottom stop is at zero, and the top stop is at a distance equal to the piston stroke.
- If the **Mechanical orientation** setting is **Negative**, the top stop is at zero, and the bottom stop is at a distance equal to the piston stroke.

The block is a composite component built from Simscape Foundation blocks. For more information on how the Double-Acting Actuator (TL-G) block works, see the reference pages of the constituent blocks:

- Translational Mechanical Converter (TL)
- Translational Mechanical Converter (G)
- Translational Hard Stop
- Ideal Translational Motion Sensor



## Ports

### Output

#### P – Piston position, m

physical signal

Physical signal output port associated with the piston position. The measurement is absolute. The first reading is the value of the **Piston initial displacement** parameter.

**Conserving****A – Inlet to chamber A**

thermal liquid

Thermal liquid conserving port associated with the inlet to chamber A.

**B – Inlet to chamber B**

gas

Gas conserving port representing the inlet to chamber B.

**R – Actuator piston**

mechanical translational

Mechanical translational conserving port representing the actuator piston.

**C – Actuator casing**

mechanical translational

Mechanical translational conserving port representing the actuator casing.

**HA – Chamber A heat flow**

thermal

Thermal conserving port associated with the surface through which heat exchange can occur between the thermal liquid volume and the actuator surroundings. The thermal processes at this port influence the temperature in the thermal liquid chamber and therefore at port **A**.

**HB – Chamber B heat flow**

thermal

Thermal conserving port associated with the surface through which heat exchange can occur between the gas volume and the actuator surroundings. The thermal processes at this port influence the temperature in the gas chamber and therefore at port **A**.

**Parameters****Thermal Liquid Side****Mechanical orientation – Direction of motion of the piston relative to the direction of flow of the fluid**

Positive | Negative

Orientation of the actuator piston relative to the direction of fluid flow. A positive orientation causes the piston to move in the positive direction relative to the actuator casing in response to a positive flow rate through port A. The mechanical orientation affects the placement of the piston hard stops. See the block description for more information on the hard stop placement.

**Piston cross-sectional area in chamber A – Cross-sectional area of the fluid volume in the thermal liquid chamber**0.01 m<sup>2</sup> (default) | scalar in units of area

Area normal to the direction of flow in the body of the thermal liquid chamber. The block uses this area to calculate the hydraulic force due to the fluid pressure in the thermal liquid chamber. This parameter must be greater than zero.

**Piston stroke — Distance of travel of the piston from hard stop to hard stop**

0.2 m (default) | scalar in units of length

Total distance of travel available to the piston, from one hard stop to the other. The hard stops limit the piston motion so that the piston is confined to stroke of the piston. See the block description for more information on the locations of the hard stops.

**Piston initial displacement — Position of the piston at the start of simulation**

0 m (default) | scalar in units of length

Absolute position of the piston at the start of simulation. The zero position coincides with the lower hard stop if the mechanical orientation is positive and with the upper hard stop if the mechanical orientation is negative.

**Dead volume in chamber A — Fluid volume in the thermal liquid chamber in the bottomed-out position**

1e-4 m<sup>3</sup> (default) | scalar in units of volume

Thermal liquid volume remaining in the thermal liquid chamber when the piston is pressed against the hard stop closest to the thermal liquid inlet. The dead volume enables the block to capture the internal states of the thermal liquid volume—its pressure and temperature—when this volume is at a minimum. This parameter must be greater than zero.

**Fluid dynamic compressibility — Choice to model the effects of dynamic compressibility inside the thermal liquid chamber**

On (default) | Off

Option to model the effects of dynamic compressibility inside the thermal liquid chamber. The thermal liquid is treated as compressible if this parameter is set to On and as incompressible if it is set to Off. The block ignores the dependence of the thermal liquid density on pressure and temperature if Off is selected.

**Initial liquid pressure in chamber A — Absolute pressure in the thermal liquid chamber**

0.101325 Pa (default) | scalar in units of pressure

Pressure inside the thermal liquid chamber at simulation time zero relative to absolute zero. This parameter helps set the initial states of the thermal liquid volume.

**Dependencies**

This parameter is enabled when the **Compressibility** parameter is set to On.

**Initial liquid temperature in chamber A — Temperature in the thermal liquid chamber at the start of simulation**

293.15 K (default) | scalar in units of temperature

Average temperature inside the thermal liquid chamber at the start of simulation. This parameter helps set the initial states of the thermal liquid volume.

**Environment pressure specification — Choice of atmospheric or custom environment pressure for the thermal liquid side**

Atmospheric pressure (default) | Specified pressure

Option to set the environment pressure of the thermal liquid chamber to the typical value of one earth atmosphere or to a custom value. Selecting Specified pressure exposes an additional parameter, **Environment pressure**, that you use to specify a custom pressure.

**Environment pressure — Absolute pressure of the environment outside the thermal liquid chamber**

0.101325 MPa (default) | scalar in units of pressure

Pressure outside the thermal liquid chamber relative to absolute zero. This pressure acts against the pressure inside the thermal liquid chamber. A pressure of zero corresponds to a perfect vacuum.

**Dependencies**

This parameter is enabled when the **Environment pressure specification** is set to Specified pressure.

**Gas Side****Piston cross-sectional area in chamber B — Cross-sectional area of the fluid volume in the gas chamber**1e-3 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow in the body of the gas chamber. The block uses this area to calculate the pneumatic force due to the fluid pressure in the gas chamber. This parameter must be greater than zero.

**Cross-sectional area at port B — Cross-sectional area of the inlet of the gas chamber**1e-3 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow at the entrance to the gas chamber. The cross-sectional area at the entrance can differ from that in the body of the chamber. Set the two cross-sectional areas to different values to model the effects of a sudden area change at the inlet. This parameter must be greater than zero.

**Dead volume in chamber B — Fluid volume in the gas chamber in the bottomed-out state**1e-4 m<sup>3</sup> (default) | positive scalar in units of volume

Gas volume remaining in the gas chamber when the piston is pressed against the hard stop closest to the gas inlet. The dead volume enables the block to capture the internal states of the gas volume—its pressure and temperature—when this volume is at a minimum. This parameter must be greater than zero.

**Initial gas pressure (absolute) — Absolute pressure inside the gas chamber at the start of simulation**

0.101325 MPa (default) | scalar in units of pressure

Pressure inside the gas chamber at simulation time zero relative to absolute zero. This pressure helps set the initial state of the gas volume.

**Environment pressure specification — Choice of atmospheric or custom environment pressure for the gas side**

Atmospheric pressure (default) | Specified pressure

Option to set the environment pressure of the gas chamber to the typical value of one earth atmosphere or to a custom value. Selecting **Specified pressure** exposes an additional parameter, **Environment pressure**, that you use to specify a custom pressure.

**Environment pressure — Absolute pressure of the environment outside the gas chamber**

0.101325 MPa (default) | scalar in units of pressure

Pressure outside the gas chamber relative to absolute zero. This pressure acts against the pressure inside the gas chamber. A pressure of zero corresponds to a perfect vacuum.

**Dependencies**

This parameter is enabled when the **Environment pressure specification** is set to **Specified pressure**.

**Hard Stop**

**Hard-stop stiffness coefficient — Stiffness coefficient for the restorative portion of the hard-stop contact force**

1e6 N/m (default) | scalar in units of force/length

Spring coefficient for use in the spring-damper model of the piston hard-stops. The spring force is assumed to be the same at both hard stops. Increase the coefficient value to model harder contact.

**Hard-stop damping coefficient — Damping coefficient for the dissipative portion of the hard-stop contact force**

150 N/(m/s) (default) | scalar in units of force/velocity

Damping coefficient for use in the spring-damper model of the piston hard stops. The damping force is assumed to be the same at both hard stops. Increase the coefficient value to reduce piston bounce on contact.

**Hard stop model — Modeling approach for hard stops**

Stiffness and damping applied smoothly through transition region (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Modeling approach for hard stops. Options include:

- **Stiffness and damping applied smoothly through transition region** — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- **Full stiffness and damping applied at bounds, undamped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- **Full stiffness and damping applied at bounds, damped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied. This is the hard-stop model used in previous releases.

**Transition region — Distance below which scaling is applied to the hard-stop force**

0.1 mm (default) | scalar in units of length

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value specified here. It is at its full value when the distance to the hard stop is zero.

## **Version History**

**Introduced in R2016b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Double-Acting Actuator (TL) | Double-Acting Actuator (G-IL) | Double-Acting Actuator (H-G) | Double-Acting Hydraulic Cylinder | Double-Acting Hydraulic Cylinder (Simple)

## Double-Acting Hydraulic Cylinder

Hydraulic actuator exerting force in both directions

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Hydraulic Cylinders



### Description

The Double-Acting Hydraulic Cylinder block models a device that converts hydraulic energy into mechanical energy in the form of translational motion. Hydraulic fluid pumped under pressure into one of the two cylinder chambers forces the piston to move and exert force on the cylinder rod. Double-acting cylinders transfer force and motion in both directions.

Connections **R** and **C** are mechanical translational conserving ports corresponding to the cylinder rod and cylinder clamping structure, respectively. Connections **A** and **B** are hydraulic conserving ports. Port **A** is connected to converter **A** and port **B** is connected to converter **B**.

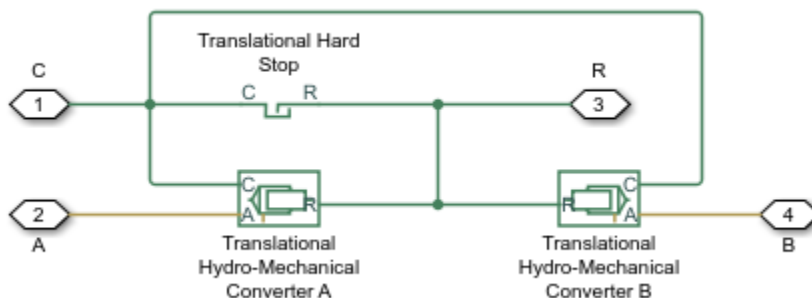
The energy through hydraulic port **A** or **B** is directed to the appropriate Translational Hydro-Mechanical Converter block. The converter transforms hydraulic energy into mechanical energy and accounts for the fluid compressibility in the cylinder chamber. The rod motion is limited with the mechanical Translational Hard Stop block in such a way that the rod can travel only between cylinder caps.

### Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Cylinder orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber A volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

### Composite Structure

The model of the cylinder is built of Simscape Foundation library blocks. The schematic diagram of the model is shown below.





## Assumptions and Limitations

- No leakage, internal or external, is taken into account.
- No loading on piston rod, such as inertia, friction, spring, and so on, is taken into account. If necessary, you can easily add them by connecting an appropriate building block to cylinder port R.

## Ports

### Input

#### **p — Piston position, m**

physical signal

Piston displacement from cap A, received as a physical signal from a Simscape Multibody block.

### Dependencies

To enable this port, set the **Piston displacement from cap A** parameter to Provide input signal from Multibody joint.

### Conserving

#### **A — Hydraulic conserving port associated with the cylinder chamber A**

hydraulic

Hydraulic conserving port associated with the cylinder chamber A.

#### **B — Hydraulic conserving port associated with the cylinder chamber B**

hydraulic

Hydraulic conserving port associated with the cylinder chamber B.

#### **R — Mechanical translational conserving port associated with the cylinder rod**

mechanical translational

Mechanical translational conserving port associated with the cylinder rod.

#### **C — Mechanical translational conserving port associated with the cylinder clamping structure**

mechanical translational

Mechanical translational conserving port associated with the cylinder clamping structure.

## Parameters

### Basic Parameters

#### **Piston area B — Chamber B effective piston area**

$0.5e-3 \text{ m}^2$  (default) | positive scalar

Chamber B effective piston area.

#### **Piston stroke — Piston maximum travel between caps**

$0.1 \text{ m}$  (default) | positive scalar

Piston maximum travel between caps.

**Dead volume A — Fluid volume in chamber A that remains in the chamber after the rod is fully retracted**

1e-4 m<sup>3</sup> (default) | positive scalar

Fluid volume in chamber A that remains in the chamber after the rod is fully retracted.

**Dead volume B — Fluid volume in chamber B that remains in the chamber after the rod is fully extended**

1e-4 m<sup>3</sup> (default) | positive scalar

Fluid volume in chamber B that remains in the chamber after the rod is fully extended.

**Specific heat ratio — Specific heat ratio used in compressibility calculations**

1.4 (default) | positive scalar greater than 1

Specific heat ratio used in compressibility calculations. This parameter is equivalent to the **Specific heat ratio** parameter of the Translational Hydro-Mechanical Converter block.

**Cylinder orientation — Specifies cylinder orientation with respect to the globally assigned positive direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Specifies cylinder orientation with respect to the globally assigned positive direction. The cylinder can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port **A** exerts force in negative direction, set the parameter to Pressure at A causes negative displacement of R relative to C

**Hard Stop Properties**

**Contact stiffness — Elasticity of collision**

1e6 N/m (default) | positive scalar

Specifies the elastic property of colliding bodies for the Translational Hard Stop block. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency.

**Contact damping — Dissipating property of collision**

150 N\*s/m (default) | nonnegative scalar

Specifies dissipating property of colliding bodies for the Translational Hard Stop block. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, it is recommended that you assign a nonzero value to this parameter.

**Hard stop model — Select the hard stop model**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Modeling approach for hard stops. Options include:

- **Stiffness and damping applied smoothly through transition region (default)** — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- **Full stiffness and damping applied at bounds, undamped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- **Full stiffness and damping applied at bounds, damped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied.

### **Transition region — Region where force is ramped up**

0.1 mm (default) | positive scalar

Region where the force is ramped up from zero to the full value. At the end of the transition region, the full stiffness and damping are applied.

#### **Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

#### **Initial Conditions**

### **Piston displacement from cap A — Method for determining the piston position**

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the piston position. Setting this parameter to **Provide input signal from Multibody joint** exposes the physical signal port **p**, which lets the block receive the piston position from a Simscape Multibody block.

### **Initial piston displacement from cap A — The distance that the piston is extended at the beginning of simulation**

0 m (default) | nonnegative scalar

The distance that the piston is extended at the beginning of simulation. You can set the piston position to any point within its stroke. The default value corresponds to the fully retracted position.

#### **Dependencies**

To enable this parameter, set **Piston displacement from cap A** to Calculate from velocity of port R relative to port C.

### **Chamber A initial pressure — Pressure in the cylinder chamber A at the beginning of simulation**

0 Pa (default) | nonnegative scalar

Pressure in the cylinder chamber A at the beginning of simulation.

**Chamber B initial pressure — Pressure in the cylinder chamber B at the beginning of simulation**

0 Pa (default) | nonnegative scalar

Pressure in the cylinder chamber B at the beginning of simulation.

## **Version History**

**Introduced in R2006a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Single-Acting Hydraulic Cylinder | Ideal Translational Motion Sensor | Translational Hard Stop | Translational Hydro-Mechanical Converter

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Double-Acting Hydraulic Cylinder (Simple)

Basic functionality of double-acting hydraulic cylinder



### Library

Hydraulic Cylinders

### Description

The Double-Acting Hydraulic Cylinder (Simple) block represents a simplified version of a double-acting hydraulic cylinder, developed for applications where only the basic cylinder functionality must be reproduced, in exchange for better numerical efficiency. For these reasons, such factors as fluid compressibility, friction, and leakages are assumed to be negligible. The hard stops are assumed to be fully inelastic, to eliminate any possible oscillations at the end of the stroke. The model is especially suitable for real-time and HIL (hardware-in-the-loop) simulation, if such simplifications are acceptable.

The model is described with the following equations:

$$F = A_A \cdot p_A - A_B \cdot p_B - F_c$$

$$q_A = A_A \cdot v$$

$$q_B = A_B \cdot v$$

$$\frac{dx}{dt} = v$$

$$v = v_R - v_C$$

$$F_c = \begin{cases} (x - x_E) \cdot K_p \cdot v & \text{if } x > x_E, v > 0 \\ (x - x_R) \cdot K_p \cdot v & \text{if } x < x_R, v < 0 \\ 0 & \text{otherwise} \end{cases}$$

$$x_E = S - x_0$$

$$x_R = -x_0$$

where

$F$	Force developed by the cylinder
$v$	Cylinder rod velocity
$v_R, v_C$	Absolute velocities of cylinder rod and cylinder case, respectively

$A_A$	Piston area at port A side
$A_B$	Piston area at port B side
$p_A$	Pressure at the cylinder port A
$p_B$	Pressure at the cylinder port B
$q_A$	Flow rate through port A into the cylinder
$q_B$	Flow rate through port B from the cylinder
$x$	Piston position
$x_0$	Initial distance between piston and cap A
$F_c$	Hard stop force
$x_E$	Distance the piston can travel to fully extend from initial position
$x_R$	Distance the piston can travel to fully retract from initial position
$K_p$	Penetration coefficient
$S$	Piston stroke

The main difference between this block and the Double-Acting Hydraulic Cylinder block is the representation of the hard stop:

- The Double-Acting Hydraulic Cylinder block utilizes the elastic model of the stop, which is essentially a combination of a spring and a damper, connected in parallel. The stiffness of the spring, which represents contact stiffness of colliding bodies, is very high, resulting in high-frequency, low-magnitude oscillations at the moment the bodies collide. These oscillations can hardly be noticed experimentally, but they are difficult to process by a numerical simulation and generally decrease numerical efficiency.
- The hard stop in the Double-Acting Hydraulic Cylinder (Simple) block is represented with the inelastic model, which is essentially a viscous damper with the penetration-dependent damping coefficient. This coefficient is referred to as the penetration coefficient. With inelastic model, no oscillation is generated during an impact, resulting in improved numerical robustness and efficiency. But inelastic stop model has a feature that you must consider while selecting the model: colliding bodies continue slowly moving into each other as long as the contact is loaded with the compressing force. In real life, this phenomenon is similar to collision of two bodies separated by a sizable layer of viscous liquid. It takes some time to squeeze the liquid before bodies themselves come into contact.

Connections R and C are mechanical translational conserving ports corresponding to the cylinder rod and cylinder clamping structure, respectively. Connections A and B are hydraulic conserving ports. Port A is connected to chamber A and port B is connected to chamber B.

You can adjust the block directionality with the **Cylinder orientation** parameter.

## Basic Assumptions and Limitations

- Friction between moving parts is not taken into account.
- Inertia effects are not taken into account.
- Fluid compressibility is not taken into account.
- Leakage flows are assumed to be negligible.
- The hard stops are assumed to be fully inelastic, as explained above.

## Parameters

### Piston area A

Chamber A effective piston area. The default value is  $0.001 \text{ m}^2$ .

### Piston area B

Chamber B effective piston area. The default value is  $5e-4 \text{ m}^2$ .

### Piston stroke

Piston maximum travel between caps. The default value is  $0.1 \text{ m}$ .

### Piston initial distance from cap A

The distance between the piston and cap A at the beginning of simulation. This value cannot exceed the piston stroke. The default value is  $0$ .

### Penetration coefficient

Specifies the penetration property of colliding bodies. The higher the value of the coefficient, the less the bodies penetrate into each other, but the sharper the increase of the impact force. To find out the value of the coefficient for a particular application, it is recommended to run the same model with different hard stop models (or with different cylinder models) until they show close results. The default value of the coefficient is  $1e12 \text{ N/m/(m/s)}$ .

### Cylinder orientation

Specifies cylinder orientation with respect to the globally assigned positive direction. The cylinder can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A exerts force in negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Cylinder orientation**

All other block parameters are available for modification.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the cylinder chamber A.

B

Hydraulic conserving port associated with the cylinder chamber B.

R

Mechanical translational conserving port associated with the cylinder rod.

C

Mechanical translational conserving port associated with the cylinder clamping structure.

## Examples

The “Closed-Loop Hydraulic Actuator Model for Real-Time Simulation” example shows how to use this cylinder along with other blocks optimized for real-time and HIL simulation.

## Version History

Introduced in R2010a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

[Double-Acting Hydraulic Cylinder](#) | [Single-Acting Hydraulic Cylinder](#) | [Single-Acting Hydraulic Cylinder \(Simple\)](#) | [Translational Hard Stop](#) | [Translational Hydro-Mechanical Converter](#)

## Topics

[“Upgrading Simscape Fluids Models Containing Hydraulics \(Isothermal\) Blocks”](#)



## Double-Acting Rotary Actuator (IL)

Double-acting rotary actuator in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators



### Description

The Double-Acting Rotary Actuator (IL) block models a rotary actuator in an isothermal liquid network. The actuator converts the pressure differential between two chambers into mechanical torque. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models.

Ports **A** and **B** are the isothermal liquid conserving ports associated with inlets of chamber A and chamber B, respectively. Port **R** is associated with the actuator shaft and port **C** is associated with the reference actuator casing. If **Mechanical orientation** is set to **Pressure at A causes positive rotation of R relative to C**, the pressure in chamber A causes a positive rotation of the shaft at port **R** relative to port **C**. When the shaft angle is calculated internally, the physical signal port **q** reports the shaft angle. When the angle is set by a connection to a Simscape Multibody joint, it is received as a physical signal at port **q**.

### Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Rotational Multibody Interface block connection to a Simscape Multibody joint.

### Hard Stop Model

To avoid mechanical damage to an actuator when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Single-Acting Rotary Actuator (IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.
- Full stiffness and damping applied at bounds, damped rebound.

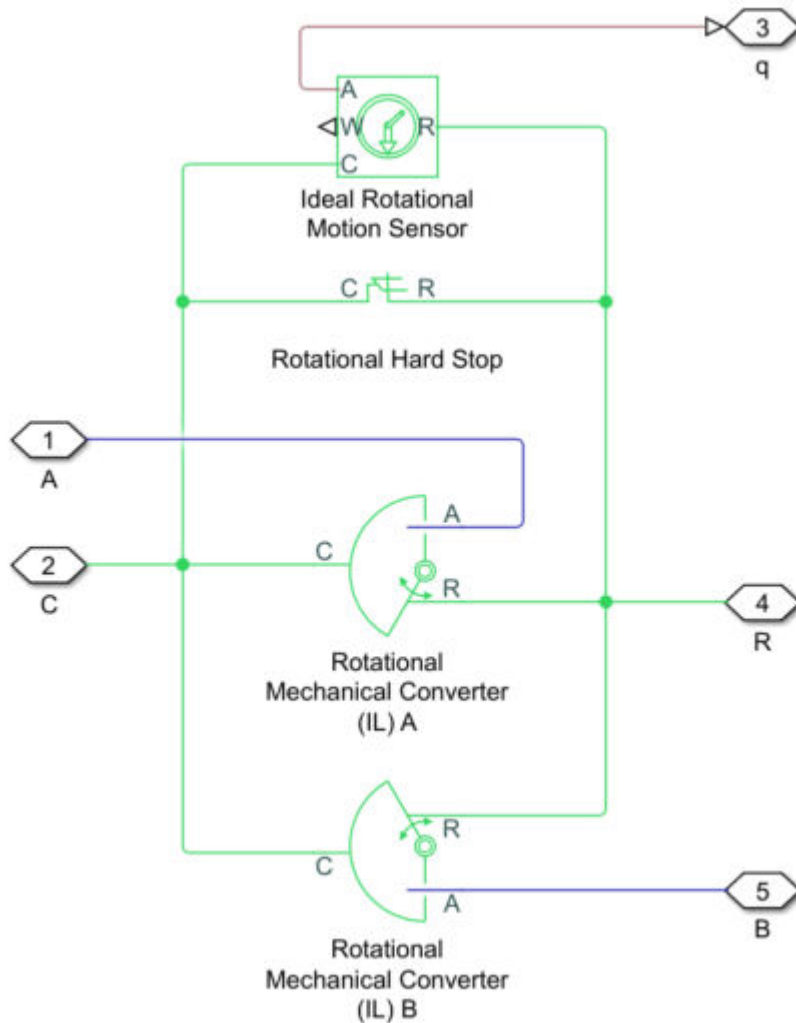
The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

For more information about these settings, see the Rotational Hard Stop block page.

## Block Schematics

The Double-Acting Rotary Actuator (IL) block comprises three Foundation Library blocks:

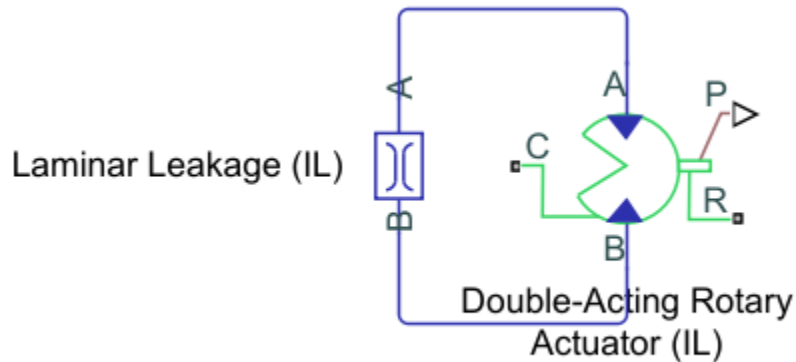
- Ideal Rotational Motion Sensor
- Rotational Hard Stop
- Rotational Mechanical Converter (IL)



## Underlying Block Components

### Leakage

Laminar leakage is not accounted for in the Double-Acting Rotary Actuator (IL) block. To include leakage in your simulation, set the **Cross-sectional geometry** parameter to **Custom** and connect ports **A** and **B** to ports **A** and **B** of a Laminar Leakage (IL) block.



## Adding Leakage to the Simulation

### Ports

#### Input

##### **q – Shaft angle**

physical signal

Shaft angle, received as a physical signal from a Simscape Multibody block.

#### Dependencies

To expose this port, set **Shaft rotation from chamber A** to Provide input signal from Multibody joint.

#### Output

##### **q – Actuator angle**

physical signal

Physical signal output port associated with the shaft angular position.

#### Dependencies

To expose this port, set **Shaft rotation from chamber A** to Calculate from angular velocity of port R relative to port C.

### Conserving

##### **A – Chamber A inlet**

isothermal liquid

Isothermal liquid conserving port associated with the actuator chamber A.

##### **B – Chamber B inlet**

isothermal liquid

Isothermal liquid conserving port associated with the actuator chamber B.

**R – Actuator shaft**

mechanical rotational

Mechanical rotational conserving port associated with the shaft.

**C – Actuator casing**

mechanical rotational

Mechanical rotational conserving port associated with the cylinder case.

**Parameters****Actuator****Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port **A** is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port **A** is expanding. This corresponds to rod contraction.

**Volume displacement in chamber A – Volume displacement** $1e-4 \text{ m}^3/\text{rad}$  (default) | positive scalar

Effective displacement of the actuator in chamber A.

**Volume displacement in chamber B – Volume displacement** $1e-4 \text{ m}^3/\text{rad}$  (default) | positive scalar

Effective displacement of the actuator in chamber B.

**Stroke – Angle** $5.0 \text{ rad}$  (default) | positive scalar

Shaft maximum travel between stops.

**Dead volume in chamber A – Fluid volume** $1e-5 \text{ m}^3$  (default) | positive scalarVolume of liquid when the piston displacement is  $\theta$  in chamber A. This is the liquid volume when the piston is up against the actuator end cap.**Dead volume in chamber B – Fluid volume** $1e-5 \text{ m}^3$  (default) | positive scalarVolume of liquid when the piston displacement is  $\theta$  in chamber B. This is the liquid volume when the piston is up against the actuator end cap.

**Environment pressure specification — Pressure reference source**

Atmospheric pressure (default) | Specified pressure

Choice of environment pressure. Options include Atmospheric pressure and Specified pressure.

**Environment pressure — User-defined pressure reference**

0.101325 MPa (default) | positive scalar

Pressure outside the actuator casing. This pressure acts against the pressures inside the actuator chambers. A value of zero corresponds to a vacuum.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Hard Stop****Hard stop stiffness coefficient — Stiffness coefficient**

1e6 N\*m/rad (default) | positive scalar

Specifies the elasticity for the Rotational Hard Stop block. The greater the value of the parameter, the more rigid the impact between the rod and the stop becomes. Lower values result in softer contact and generally improve simulation efficiency and convergence.

**Hard stop damping coefficient — Damping coefficient**

150 N\*m(rad/s) (default) | positive scalar

Specifies the dissipating property of colliding bodies for the Rotational Hard Stop block. At zero damping, the impact is elastic. The greater the value of the parameter, the greater the energy dissipation during piston-stop interaction. Damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. Set this parameter to a nonzero value to improve the efficiency and convergence of your simulation.

**Hard stop model — Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Rotational Hard Stop block for more information.

**Transition region — Transition region**

0.001 rad (default) | positive scalar

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value of this parameter. The contact force is at its full value when the distance to the hard stop is zero.

**Initial Conditions****Shaft rotation from chamber A — Method for determining shaft angle**

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the shaft angle. The block can receive the angle from a Multibody block when set to **Provide input signal from Multibody joint**, or calculates the angle internally, which is reported at port **q**.

**Initial shaft rotation from chamber A — Initial rotation**

0 rad (default) | scalar

The position of the actuator at the beginning of simulation. This value falls between 0 and the value of the **Stroke** in the positive orientation, and 0 and the negative value of the **Stroke** in the negative orientation.

**Dependencies**

To enable this parameter, set **Shaft rotation from chamber A** to **Calculate from velocity of port R relative to port C**.

**Fluid dynamic compressibility — Fluid compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to **On**, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

**Initial liquid pressure in chamber A — Liquid pressure**

0.101325 MPa (default) | positive scalar

Pressure in actuator chamber A at the start of simulation.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to **On**.

**Initial liquid pressure in chamber B — Liquid pressure**

0.101325 MPa (default) | positive scalar

Pressure in actuator chamber B at the start of simulation.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to **On**.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Double-Acting Actuator (IL) | Double-Acting Actuator (G-IL) | Single-Acting Rotary Actuator (IL) | Rotating Single-Acting Actuator (IL) | Single-Acting Actuator (IL)

**Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”

# Double-Acting Rotary Actuator

Double-acting hydraulic rotary actuator



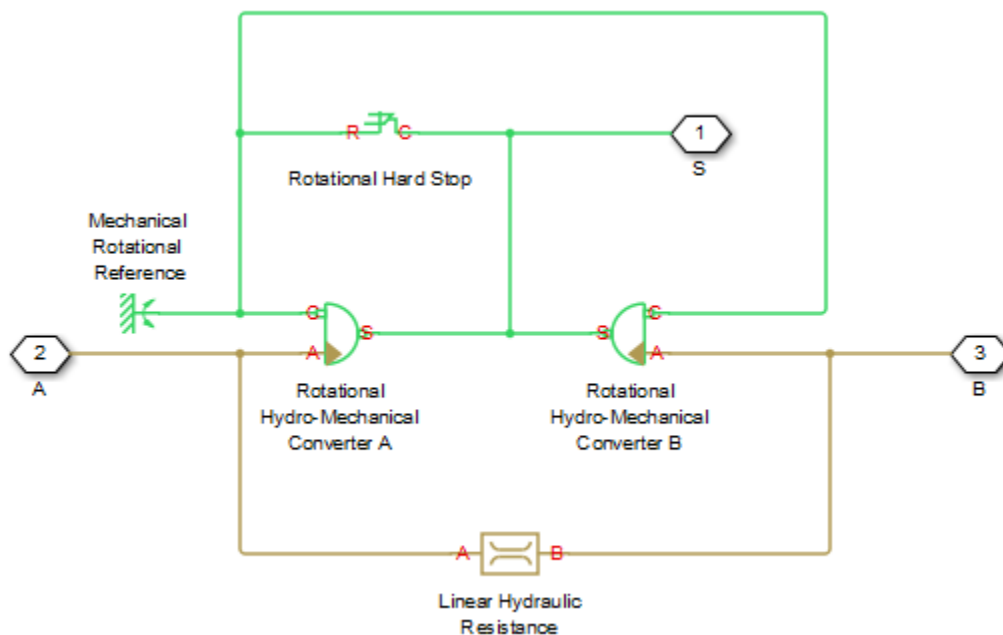
## Library

Hydraulic Cylinders

## Description

The Double-Acting Rotary Actuator block models a double-acting hydraulic rotary actuator, which directly converts hydraulic energy into mechanical rotational energy without employing intermediary transmissions such as rack-and-pinion, sliding spline, chain, and so on. Hydraulic fluid pumped under pressure into one of the two actuator chambers forces the shaft to rotate and generate torque. Double-acting actuators generate torque and motion in both directions.

The model of the actuator is built of Simscape Foundation library blocks. The schematic diagram of the model is shown below.



The blocks in the diagram perform the following functions:



Rotational Hydro-Mechanical Converter A	Converts hydraulics energy into mechanical rotational energy when fluid is pumped into actuator chamber A, while accounting for fluid compressibility.
Rotational Hydro-Mechanical Converter B	Converts hydraulics energy into mechanical rotational energy when fluid is pumped into actuator chamber B, while accounting for fluid compressibility.
Rotational Hard Stop	Imposes limits on shaft rotation.
Linear Hydraulic Resistance	Accounts for leakages.

Connections A and B are hydraulic conserving ports. Port A is connected to chamber A and port B is connected to chamber B. Connection S is a mechanical rotational conserving port associated with the actuator shaft.

The block directionality is adjustable and can be controlled with the **Actuator orientation** parameter.

## Basic Assumptions and Limitations

No loading, such as inertia, friction, spring, and so on, is taken into account. If necessary, you can easily add them by connecting an appropriate building block to port S.

## Parameters

### Actuator displacement

Effective displacement of the actuator. The default value is  $4.5e-5 \text{ m}^3/\text{rad}$ .

### Shaft stroke

Shaft maximum travel between stops. The default value is  $5.1 \text{ rad}$ .

### Shaft initial angle

The position of the shaft at the beginning of simulation. You can set the shaft position to any angle within its stroke. The default value is  $0$ , which corresponds to the shaft position at the very beginning of the stroke.

### Dead volume A

Fluid volume in chamber A that remains in the chamber when the shaft is positioned at the very beginning of the stroke. The default value is  $1e-4 \text{ m}^3$ .

### Dead volume B

Fluid volume in chamber B that remains in the chamber when the shaft is positioned at the end of the stroke. The default value is  $1e-4 \text{ m}^3$ .

### Leak coefficient

Leak coefficient for the Linear Hydraulic Resistance block. The default value is  $1e-14 \text{ (m}^3/\text{s)/Pa}$ .

### Specific heat ratio

Gas-specific heat ratio for the Hydraulic Piston Chamber block. The default value is  $1.4$ .

### Contact stiffness

Specifies the elastic property of colliding bodies for the Rotational Hard Stop block. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the

impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is  $1e6$  N\*m/rad.

### **Contact damping**

Specifies dissipating property of colliding bodies for the Rotational Hard Stop block. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, MathWorks recommends that you assign a nonzero value to this parameter. The default value is  $150$  N\*m/(rad/s).

### **Hard stop model**

Modeling approach for hard stops. Options include:

- **Stiffness and damping applied smoothly through transition region (default)** — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- **Full stiffness and damping applied at bounds, undamped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- **Full stiffness and damping applied at bounds, damped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied. This is the hard-stop model used in previous releases.

### **Transition region**

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value specified here. It is at its full value when the distance to the hard stop is zero. The default value is  $1$  mm..

### **Actuator orientation**

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it generates torque in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A generates torque in the negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

### **Global Parameters**

Parameter determined by the type of working fluid:

- **Fluid bulk modulus**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the actuator chamber A.

B

Hydraulic conserving port associated with the actuator chamber B.

S

Mechanical rotational conserving port associated with the actuator shaft.

## Version History

**Introduced in R2007a**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

[Linear Hydraulic Resistance](#) | [Rotational Hard Stop](#) | [Rotational Hydro-Mechanical Converter](#)

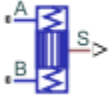
## Topics

[“Upgrading Simscape Fluids Models Containing Hydraulics \(Isothermal\) Blocks”](#)

## Double-Acting Servo Valve Actuator (IL)

Double-acting servo cylinder with spring-centered spool in an isothermal liquid system

**Library:** Simscape / Fluids / Valve Actuators & Forces



### Description

The Double-Acting Servo Valve Actuator (IL) block models a double-acting servo cylinder arranged as a spring-centered spool. The spring neutral position is where the spool is located at the middle of the stroke. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models. Fluid compressibility is optionally modeled in both piston chambers.

The physical signal output **S** reports the spool position.

### Hard Stop Model

To avoid mechanical damage to an actuator when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Double-Acting Servo Valve Actuator (IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.
- Full stiffness and damping applied at bounds, damped rebound.

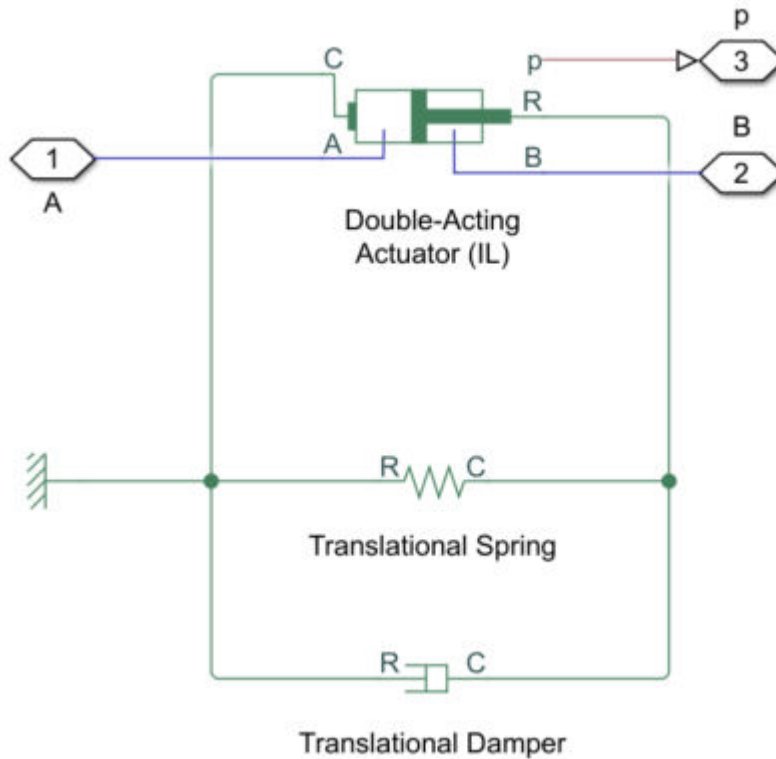
The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Spool stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

For more information about these settings, see the Translational Hard Stop block page.

### Block Schematic

The Double-Acting Servo Actuator block comprises an Isothermal Liquid library block and two Simscape Foundation blocks:

- Double-Acting Actuator (IL)
- Translational Spring
- Translational Damper



## Ports

### Conserving

#### **A – Liquid port for chamber A**

isothermal liquid

Isothermal liquid conserving port associated with the liquid inlet of chamber A.

#### **B – Liquid port for chamber B**

isothermal liquid

Isothermal liquid conserving port associated with the liquid inlet of chamber B.

### Output

#### **S – Spool position, m**

physical signal

Physical signal associated with the spool position, in m. A position of zero indicates that the spool is at a neutral position in the middle of a stroke.

## Parameters

### Cylinder

#### Spool cross-sectional area — Area measurement

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the spool

#### Spool stroke — Distance

5e-3 m (default) | positive scalar

Distance the spool travels in a stroke.

#### Spring stiffness — Rate of force for the spring

1e3 N/m (default) | scalar

Spring rate of the centering springs.

#### Damping coefficient — Damping coefficient

150 N/(m/s) (default) | positive scalar

Damping coefficient in the contact between the piston and the case.

### Hard Stop

#### Hard stop stiffness coefficient — Stiffness coefficient

1e10 N/m (default) | positive scalar

Specifies the elasticity for the hard stop model. The greater the value of the parameter, the more rigid the impact between the rod and the stop becomes. Lower values result in softer contact and generally improve simulation efficiency and convergence.

#### Hard stop damping coefficient — Damping coefficient

150 N/(m/s) (default) | positive scalar

Specifies dissipating property of colliding bodies for the hard stop model. At zero damping, the impact is elastic. The greater the value of the parameter, the greater the energy dissipation during piston-stop interaction. Damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. Set this parameter to a nonzero value to improve the efficiency and convergence of your simulation.

#### Hard stop model — Model hard stops

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Modeling approach for hard stops.

- Stiffness and damping applied smoothly through transition region, damped rebound — Specify a transition region in which the torque is scaled from zero. At the end of the transition region, the full stiffness and damping are applied. This model has damping applied on the rebound, but it is limited to the value of the stiffness torque. Damping can reduce or eliminate the torque provided by the stiffness, but never exceed it. All equations are smooth and produce no zero crossings.

- **Full stiffness and damping applied at bounds, undamped rebound** — This model has full stiffness and damping applied with impact at the upper and lower bounds and no damping on the rebound. The equations produce no zero crossings when velocity changes sign, but there is a position-based zero crossing at the bounds. Having no damping on rebound helps to push the slider past this position quickly. This model has nonlinear equations.
- **Full stiffness and damping applied at bounds, damped rebound** — This model has full stiffness and damping applied with impact at the upper and lower bounds and damping applied on the rebound. The equations are switched linear, but produce position-based zero crossings. Use this hard stop model if `simscape.findNonlinearBlocks` indicates that this is the block that prevents the whole network from being switched linear.

### Transition region — Transition region

0.001 rad (default) | positive scalar

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value of this parameter. The contact force is at its full value when the distance to the hard stop is zero.

### Effects and Initial Conditions

#### Spool initial displacement — Initial location of the spool

0 m (default) | scalar

When the initial displacement of the spool is set to 0, the spool begins directly between chamber A and chamber B. A positive distance moves the spool away from chamber A, while a negative amount moves the spool toward chamber A.

#### Fluid dynamic compressibility — Fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

#### Initial liquid pressure in chamber A — Liquid pressure

0.101325 MPa (default) | positive scalar

Pressure in actuator chamber A at the start of simulation.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

#### Initial liquid pressure in chamber B — Liquid pressure

0.101325 MPa (default) | positive scalar

Pressure in actuator chamber B at the start of simulation.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

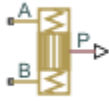
### **See Also**

Double-Acting Actuator (IL) | Double-Acting Actuator (G-IL) | Double-Acting Rotary Actuator (IL) | Single-Acting Actuator (IL)



# Double-Acting Servo Cylinder

Hydraulic double-acting servo cylinder with spring-centered plunger

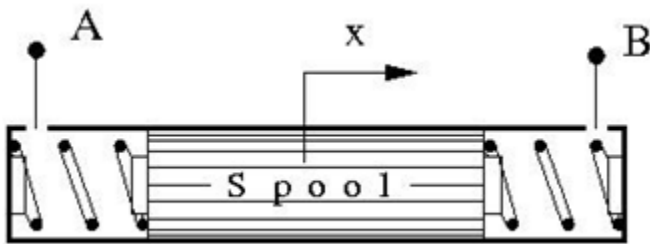


## Library

Valve Actuators

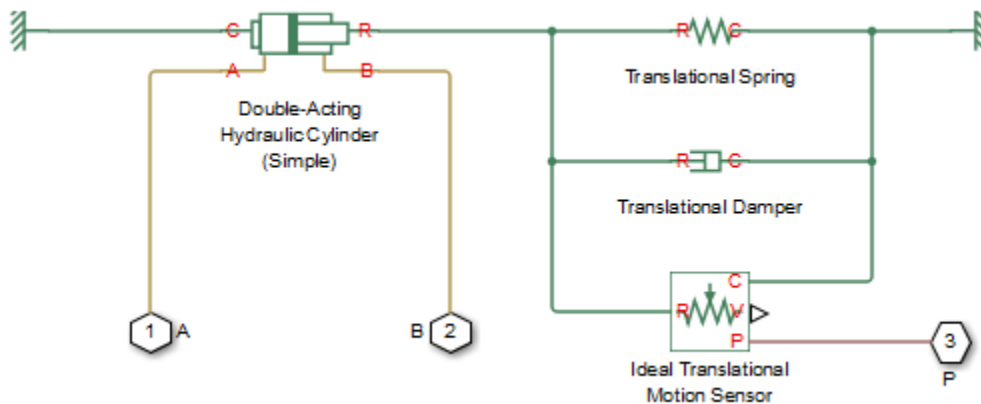
## Description

The Double-Acting Servo Cylinder block models a hydraulic double-acting servo cylinder implemented as a spring-centered plunger.



Changing pressure at ports A and B shifts the spool from the neutral position in proportion to the pressure differential. Use the servo cylinder for control purposes.

The model of the cylinder uses the Double-Acting Hydraulic Cylinder (Simple), Translational Spring, Translational Damper, and Ideal Translational Motion Sensor blocks. The following figure shows the schematic diagram of the model.



The plunger is located initially in the middle of the stroke. The plunger displacement is computed with the following equations:

$$A(p_A - p_B) = k \cdot x + B \cdot v + F_{HS}$$

$$F_{HS} = \begin{cases} (x - S/2) \cdot K_p \cdot v & \text{if } x > S/2, v > 0 \\ (x + S/2) \cdot K_p \cdot \text{abs}(v) & \text{if } x < -S/2, v < 0 \\ 0 & \text{otherwise} \end{cases}$$

where

$p_A, p_B$	Pressures at port A and B, respectively
$A$	Spool face area
$k$	Spring rate
$B$	Damping coefficient
$F_{HS}$	Hard stop force
$K_p$	Stop penetration coefficient
$S$	Piston stroke
$v$	Piston velocity
$x$	Piston displacement

Connection P is a physical signal output port that outputs the plunger displacement from the central position. Connections A and B are hydraulic conserving ports. Pressure at port A moves the plunger in the positive direction.

## Basic Assumptions and Limitations

- Friction between moving parts is not taken into account.
- Inertia effects are not taken into account.
- Fluid compressibility is not taken into account.
- Leakage flows are assumed to be negligible.
- The hard stops are assumed to be fully inelastic. For details, see the Double-Acting Hydraulic Cylinder (Simple) block reference page.

## Parameters

### Piston area

The face area of the piston. The default value is  $1e-4 \text{ m}^2$ .

### Piston stroke

The full piston stroke, from one hard stop to another. The piston is located initially in the middle of the stroke and can travel half a stroke in the positive and negative direction. The default value is  $0.005 \text{ m}$ .

### Spring rate

The spring rate of the centering springs. The default value is  $1000 \text{ N/m}$ .

**Damping coefficient**

The damping coefficient in the contact between the piston and the case. The default value is 150 N/(m/s).

**Stop penetration coefficient**

The penetration property of the piston hard stop. The hard stop is represented as absolutely inelastic, and the property is characterized by the penetration coefficient. The default value of the coefficient is 1e12 N/m/(m/s).

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the cylinder chamber A.

B

Hydraulic conserving port associated with the cylinder chamber B.

P

Physical signal output port that outputs the piston displacement.

**Version History**

**Introduced in R2013a**

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Double-Acting Hydraulic Cylinder (Simple) | Ideal Translational Motion Sensor | Translational Damper | Translational Spring

## Elbow

Hydraulic resistance in elbow



## Library

Local Hydraulic Resistances

### Description

The Elbow block represents an elbow as a local hydraulic resistance. The pressure loss is computed with the semi-empirical formula based on pressure loss coefficient, which is determined in accordance with the Crane Co. recommendations (see [1] on page 1-753, p. A-29). Two types of elbow are considered: smoothly curved (standard) and sharp-edged (miter). The block covers elbows in the 5-100 mm and 0-90 degrees range.

The block is based on the Local Resistance block. It computes the pressure loss coefficient and passes its value, as well as the critical Reynolds number value, to the Local Resistance block, which computes the pressure loss according to the formulas explained in the reference documentation for that block.

The pressure loss for turbulent flow regime is determined according to the following formula:

$$p = K \frac{\rho}{2A^2} q |q|$$

where

$q$	Flow rate
$p$	Pressure loss
$K$	Pressure loss coefficient
$A$	Elbow cross-sectional area
$\rho$	Fluid density

The flow regime is checked in the underlying Local Resistance block by comparing the Reynolds number to the specified critical Reynolds number value. For laminar flow regime, the formula for pressure loss computation is modified, as described in the reference documentation for the Local Resistance block.

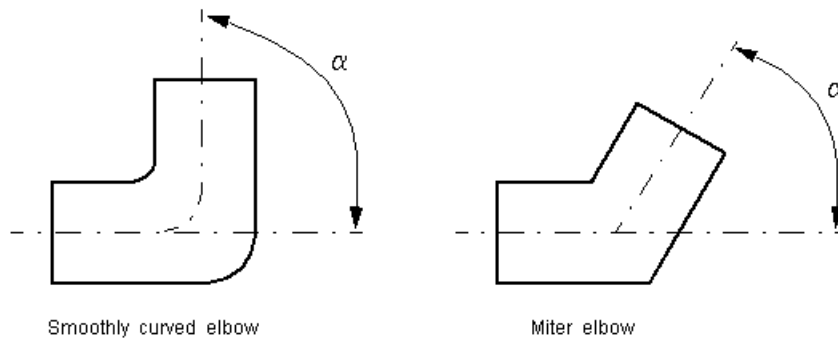
The core data for the pressure loss coefficient computation is the table-specified relationship between the friction factor  $f_T$  and the internal diameter for clean commercial steel pipes, with flow in the zone of complete turbulence (see [1] on page 1-753, p. A-26). For smoothly curved, standard 90° elbows, the pressure loss coefficient is determined with the formula

$$K = 30f_T$$

For elbows with different angles, the coefficient is corrected with the relationship presented in [2] on page 1-753, Fig.4.6:

$$K_{corr} = \alpha(0.0142 - 3.703 \cdot 10^{-5}\alpha)$$

where  $\alpha$  is the elbow angle in degrees ( $0 \leq \alpha \leq 90$ ).



Therefore, the pressure loss coefficient for smoothly curved, standard elbows is determined with the formula

$$K_{SCE} = 30f_T \cdot \alpha(0.0142 - 3.703 \cdot 10^{-5}\alpha)$$

For sharp-edged, miter bends the pressure loss coefficient is determined according to the table provided in [1] on page 1-753, p. A-29, as a function of the elbow diameter and angle

$$K_{ME} = f(d, \alpha)$$

where  $5 \leq d \leq 100$  mm and  $0 \leq \alpha \leq 90$  degrees.

Connections A and B are conserving hydraulic ports associated with the block inlet and outlet, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure differential is determined as  $p = p_A - p_B$ .

---

**Warning** The formulas used in the Elbow block are very approximate, especially in the laminar and transient flow regions. For more accurate results, use the Local Resistance block with a table-specified  $K=f(Re)$  relationship.

---

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- The elbow is assumed to be made of a clean commercial steel pipe.

## Parameters

### Elbow type

The parameter can have one of two values: `Smoothly curved` or `Sharp-edged (miter)`. The default value is `Smoothly curved`.

### Elbow internal diameter

The internal diameter of the pipe. The value must be in the range between 5 and 100 mm. The default value is `0.01 m`.

### Elbow angle

The angle of the bend. The value must be in the range between 0 and 90 degrees. The default value is `90 deg`.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- `Pressure ratio` — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- `Reynolds number` — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is `0.999`. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is `80`. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Elbow type**
- **Laminar transition specification**

All other block parameters are available for modification.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the elbow inlet.

B

Hydraulic conserving port associated with the elbow outlet.

## References

[1] *Flow of Fluids Through Valves, Fittings, and Pipe*, Crane Valves North America, Technical Paper No. 410M

[2] George R. Keller, *Hydraulic System Analysis*, Published by the Editors of Hydraulics & Pneumatics Magazine, 1970

## Version History

Introduced in R2006b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Gradual Area Change | Local Resistance | Pipe Bend | Sudden Area Change | T-junction

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Elbow (IL)

Pipe turn in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Elbow (IL) block models flow in a pipe turn in an isothermal liquid network. Pressure losses due to pipe turns are calculated, but the effect of viscous friction is omitted.

Two **Elbow type** settings are available: Smoothly-curved and Sharp-edged (Miter). For a smooth pipe with a 90° bend and modeled losses due to friction, you can also use the Pipe Bend (IL) block.

### Loss Coefficients

For smoothly-curved pipe segments, the loss coefficient is calculated as:

$$K = 30f_T C_{angle}.$$

$C_{angle}$ , the angle correction factor, is calculated from Keller [2] as:

$$C_{angle} = 0.0148\theta - 3.9716 \cdot 10^{-5}\theta^2,$$

where  $\theta$  is the **Bend angle** in degrees. The friction factor,  $f_T$ , is defined for clean commercial steel. The values are interpolated from tabular data based on the internal elbow diameter for  $f_T$  provided by Crane [1]:

**PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE  
WITH FLOW IN ZONE OF COMPLETE TURBULENCE**

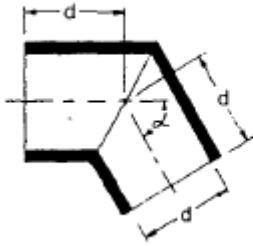
Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_T$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

The values provided by Crane are valid for diameters up to 600 mm. The friction factor for larger diameters or for wall roughness beyond this range is calculated by nearest-neighbor extrapolation.

For sharp-edged pipe segments, the loss coefficient  $K$  is calculated for the bend angle,  $\alpha$ , according to Crane [1]:



## MITRE BENDS



$\alpha$	$K$
$0^\circ$	$2 f_r$
$15^\circ$	$4 f_r$
$30^\circ$	$8 f_r$
$45^\circ$	$15 f_r$
$60^\circ$	$25 f_r$
$75^\circ$	$40 f_r$
$90^\circ$	$60 f_r$

**Mass Flow Rate**

Mass is conserved through the pipe segment:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the elbow is calculated as:

$$\dot{m} = A \sqrt{\frac{2\bar{\rho}}{K}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $A$  is the flow area.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the pipe segment pressure difference,  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\bar{\rho}}{2} K \left( \frac{\nu Re_{crit}}{D} \right)^2,$$

where

- $\nu$  is the fluid kinematic viscosity.
- $D$  is the elbow internal diameter.

**Energy Balance**

The block balances energy such that

$$\Phi_A + \Phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Liquid entry or exit port to the pipe segment.

#### **B – Liquid port**

isothermal liquid

Liquid entry or exit port to the pipe segment.

## Parameters

### **Elbow type – Bend geometry**

Smoothly curved (default) | Sharp-edged (Miter)

Bend specification of the pipe segment. A sharp-edged, or mitre, bend introduces a sharp change in flow direction, such as at a pipe joint, and the flow losses are modeled by a separate set of empirical data from gradually-turning pipe segments.

### **Elbow internal diameter – Pipe internal diameter**

0.01 m (default) | positive scalar

Internal diameter of the pipe elbow segment.

### **Elbow angle – Pipe curve angle**

90 deg (default) | positive scalar

Angle of the swept pipe curve.

### **Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the pipe segment.

## Version History

Introduced in R2020a

## References

[1] Crane Co. *Flow of Fluids Through Valves, Fittings, and Pipe TP-410*. Crane Co., 1981.

[2] Keller, G. R. *Hydraulic System Analysis*. Penton, 1985.

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pipe Bend (IL) | T-Junction (IL) | Local Resistance (IL) | Area Change (IL) | Pipe (IL) | Partially Filled Pipe (IL)

## Elbow (TL)

Pipe turn in a thermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Elbow (TL) block represents flow in a pipe turn in a thermal liquid network. Pressure losses due to pipe turns are calculated, but the block omits the effects of viscous friction.

Two **Elbow type** settings are available: Smoothly-curved and Sharp-edged (Miter). For a smooth pipe with a 90° bend and losses due to friction, you can also use the Pipe Bend (TL) block.

### Loss Coefficients

For smoothly-curved pipe segments, the loss coefficient is calculated as:

$$K = 30f_T C_{angle}.$$

$C_{angle}$ , the angle correction factor, is calculated from Keller [2] as:

$$C_{angle} = 0.0148\theta - 3.9716 \cdot 10^{-5}\theta^2,$$

where  $\theta$  is the **Bend angle** in degrees. The friction factor,  $f_T$ , is defined for clean commercial steel. The values are interpolated from tabular data based on the internal elbow diameter for  $f_T$  provided by Crane [1]:

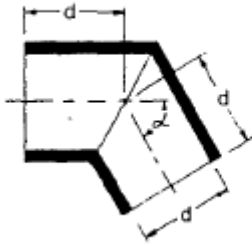
**PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE  
WITH FLOW IN ZONE OF COMPLETE TURBULENCE**

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_T$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

The values provided by Crane are valid for diameters up to 600 mm. The friction factor for larger diameters or for wall roughness beyond this range is calculated by nearest-neighbor extrapolation.

For sharp-edged pipe segments, the loss coefficient  $K$  is calculated for the bend angle,  $\alpha$ , according to Crane [1]:

## MITRE BENDS



$\alpha$	$K$
$0^\circ$	$2 f_r$
$15^\circ$	$4 f_r$
$30^\circ$	$8 f_r$
$45^\circ$	$15 f_r$
$60^\circ$	$25 f_r$
$75^\circ$	$40 f_r$
$90^\circ$	$60 f_r$

**Mass Flow Rate**

Mass is conserved through the pipe segment:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the elbow is calculated as:

$$\dot{m} = A \sqrt{\frac{2\bar{\rho}}{K}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $A$  is the flow area.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the pipe segment pressure difference,  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\bar{\rho}}{2} K \left( \frac{\nu Re_{crit}}{D} \right)^2,$$

where

- $\nu$  is the fluid kinematic viscosity.
- $D$  is the elbow internal diameter.

**Energy Balance**

The block balances energy such that

$$\Phi_A + \Phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### **A — Pipe bend entrance or exit**

thermal liquid

Thermal liquid conserving port associated with the liquid entrance or exit of the pipe bend.

#### **B — Pipe bend entrance or exit**

thermal liquid

Thermal liquid conserving port associated with the liquid entrance or exit of the pipe bend.

## Parameters

### **Elbow type — Bend geometry**

Smoothly curved (default) | Sharp-edged (Miter)

Bend specification of the pipe segment. A sharp-edged, or mitre, bend introduces a sharp change in flow direction, such as at a pipe joint, and the flow losses are modeled by a separate set of empirical data from gradually-turning pipe segments.

### **Elbow internal diameter — Pipe internal diameter**

0.01 m (default) | positive scalar

Internal diameter of the pipe elbow segment.

### **Elbow angle — Pipe curve angle**

90 deg (default) | positive scalar

Angle of the swept pipe curve.

### **Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the pipe segment.

## Version History

Introduced in R2022a

## References

[1] Crane Co. *Flow of Fluids Through Valves, Fittings, and Pipe TP-410*. Crane Co., 1981.

[2] Keller, G. R. *Hydraulic System Analysis*. Penton, 1985.

## Extended Capabilities

### **C/C++ Code Generation**

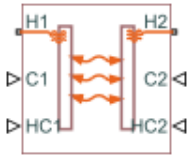
Generate C and C++ code using Simulink® Coder™.

## See Also

# E-NTU Heat Transfer

Detailed heat transfer model between two general fluids

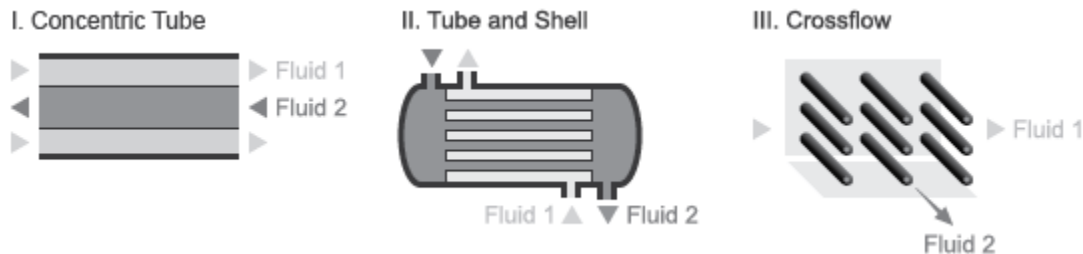
**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



## Description

The E-NTU Heat Transfer block models the heat exchange between two general fluids based on the standard Effectiveness-NTU method. The fluid thermal properties are specified explicitly through Simscape physical signals. Combine with the Heat Exchanger Interface (TL) block to model the pressure drop and temperature change between the inlet and outlet of a heat exchanger.

The block dialog box provides a choice of common heat exchanger configurations. These include concentric-pipe with parallel and counter flows, shell-and-tube with one or more shell passes, and cross-flow with mixed and unmixed flows. A generic configuration lets you model other heat exchangers based on tabular effectiveness data.



## Heat Exchanger Configurations

### Heat Transfer Rate

The E-NTU model defines the heat transfer rate between fluids 1 and 2 in terms of an effectiveness parameter  $\varepsilon$ :

$$Q_1 = -Q_2 = \varepsilon Q_{Max}, \quad 0 < \varepsilon < 1,$$

where:

- $Q_1$  and  $Q_2$  are the heat transfer rates into fluid 1 and fluid 2.
- $Q_{Max}$  is the maximum possible heat transfer rate between fluid 1 and fluid 2 at a given set of operating conditions.
- $\varepsilon$  is the effectiveness parameter.

The maximum possible heat transfer rate between the two fluids is



$$Q_{Max} = C_{Min}(T_{1,In} - T_{2,In}),$$

where:

- $C_{Min}$  is the minimum value of the thermal capacity rate:

$$C_{Min} = \min(\dot{m}_1 c_{p,1}, \dot{m}_2 c_{p,2})$$

- $T_{1,In}$  and  $T_{2,In}$  are the inlet temperatures of fluid 1 and fluid 2.
- $\dot{m}_1$  and  $\dot{m}_2$  are the mass flow rates of fluid 1 and fluid 2 into the heat exchanger volume through the inlet.
- $c_{p,1}$  and  $c_{p,2}$  are the specific heat coefficients at constant pressure of fluid 1 and fluid 2. The **Minimum fluid-wall heat transfer coefficient** parameter in the block dialog box sets a lower bound on the allowed values of the heat transfer coefficients.

### Heat Exchanger Effectiveness

The heat exchanger effectiveness calculations depend on the flow arrangement type selected in the block dialog box. For all but **Generic – effectiveness table**, the block computes the thermal exchange effectiveness through analytical expressions written in terms of the number of transfer units (NTU) and thermal capacity ratio. The number of transfer units is defined as

$$NTU = \frac{U_{Overall} A_{Heat}}{C_{Min}} = \frac{1}{C_{Min} R_{Overall}},$$

where:

- $NTU$  is the number of transfer units.
- $U_{Overall}$  is the overall heat transfer coefficient between fluid 1 and fluid 2.
- $R_{Overall}$  is the overall thermal resistance between fluid 1 and fluid 2.
- $A_{Heat}$  is aggregate area of the primary and secondary, or finned, heat transfer surfaces.

The thermal capacity ratio is defined as

$$C_{rel} = \frac{C_{Min}}{C_{Max}}$$

where:

- $C_{rel}$  is the thermal capacity ratio.

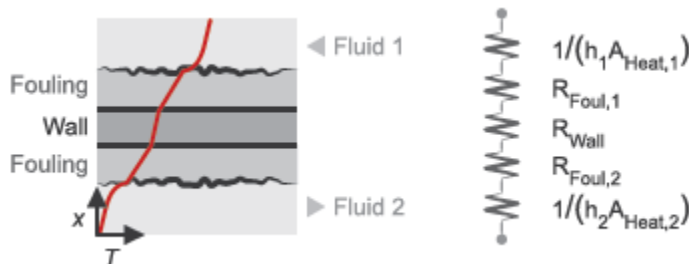
The overall heat transfer coefficient and thermal resistance used in the NTU calculation are functions of the heat transfer mechanisms at work. These mechanisms include convective heat transfer between the fluids and the heat exchanger interface and conduction through the interface wall [2 on page 1-767]:

$$R_{Overall} = \frac{1}{U_{Overall} A_{Heat}} = \frac{1}{h_1 A_{Heat,1}} + R_{Foul,1} + R_{Wall} + R_{Foul,2} + \frac{1}{h_2 A_{Heat,2}},$$

where:

- $h_1$  and  $h_2$  are the heat transfer coefficients between fluid 1 and the interface wall and between fluid 2 and the interface wall.

- $A_{Heat,1}$  and  $A_{Heat,2}$  are the heat transfer surface areas on the fluid-1 and fluid-2 sides.
- $R_{Foul,1}$  and  $R_{Foul,2}$  are the fouling resistances on the fluid-1 and fluid-2 sides.
- $R_{Wall}$  is the interface wall thermal resistance.



### Heat Transfer From Fluid 1 to Fluid 2

The tables show some of the analytical expressions used to compute the heat exchange effectiveness [1 on page 1-767]. The parameter  $N$  refers to the number of shell passes and the parameter  $\varepsilon_1$  to the effectiveness for a single shell pass.

<b>Concentric Tubes</b>	
Counter Flow	$\varepsilon = \begin{cases} \frac{1 - \exp[-NTU(1 - C_{rel})]}{1 - C_{rel}\exp[-NTU(1 - C_{rel})]}, & \text{if } C_{rel} < 1 \\ \frac{NTU}{1 + NTU}, & \text{if } C_{rel} = 1 \end{cases}$
Parallel Flow	$\varepsilon = \frac{1 - \exp[-NTU(1 + C_{rel})]}{1 + C_{rel}}$
<b>Shell and Tube</b>	
One shell pass and two, four, or six tube passes	$\varepsilon_1 = \frac{2}{1 + C_{rel} + \sqrt{1 + C_{rel}^2} \frac{1 + \exp(-NTU\sqrt{1 + C_{rel}^2})}{1 - \exp(-NTU\sqrt{1 + C_{rel}^2})}}$
$N$ Shell Passes and $2N$ , $4N$ , or $6N$ Tube Passes	$\varepsilon = \frac{[(1 - \varepsilon_1 C_{rel}) / (1 - \varepsilon_1)]^N - 1}{[(1 - \varepsilon_1 C_{rel}) / (1 - \varepsilon_1)]^N - C_{rel}}$
<b>Cross Flow (Single Pass)</b>	
Both Fluids Unmixed	$\varepsilon = 1 - \exp\left(\frac{\exp(-C_{rel}NTU^{0.78}) - 1}{C_{rel}NTU^{-0.22}}\right)$
Both Fluids Mixed	$\varepsilon = \frac{1}{\frac{1}{1 - \exp(-NTU)} + \frac{C_{rel}}{1 - \exp(-C_{rel}NTU)} - \frac{1}{NTU}}$
$C_{Max}$ mixed, $C_{Min}$ unmixed	$\varepsilon = \frac{1}{C_{rel}}(1 - \exp(-C_{rel}(1 - \exp(-NTU))))$
$C_{Max}$ unmixed, $C_{Min}$ mixed	$\varepsilon = 1 - \exp\left(-\frac{1}{C_{rel}}(1 - \exp(-C_{rel}NTU))\right)$

## Assumptions and Limitations

The flows are single-phase. The heat transfer is strictly one of sensible heat. The transfer is limited to interior of the exchanger, with the environment neither gaining heat from nor providing heat to the flows—the heat exchanger is an adiabatic component.

## Ports

- H1 — Thermal conserving port associated with the inlet temperature of fluid 1
- H2 — Thermal conserving port associated with the inlet temperature of fluid 2
- C1 — Physical signal input port for the thermal capacity rate of fluid 1
- C2 — Physical signal input port for the thermal capacity rate of fluid 2
- HC1 — Physical signal input port for the heat transfer coefficient between fluid 1 and the interface wall
- HC2 — Physical signal input port for the heat transfer coefficient between fluid 2 and the interface wall

## Parameters

### Common Tab

#### Flow arrangement

Heat exchanger geometry. Common geometries that you can select include `Parallel` or `counter flow`, `Shell and tube`, and `Cross flow`. Select `Generic – effectiveness table` to model other heat exchanger geometries based on tabular effectiveness data.

In the `Parallel` or `counter flow` configuration, the relative flow directions of fluids 1 and 2 determine whether the heat exchanger is based on parallel or counter flows. The flow directions depend on the remainder of the Simscape Fluids model.

#### Number of shell passes

Number of times the flow traverses the shell before exiting.

This parameter is visible only when the **Flow arrangement** parameter is set to `Shell and tube`. The default value is 1, corresponding to a single shell pass.

#### Cross flow type

Fluid mixing configuration. The fluids can be mixed or unmixed. The block uses the mixing configuration to determine which empirical heat transfer correlations to use. This parameter is visible only when the **Flow arrangement** parameter is set to `Cross flow`. The default setting is `Both fluids mixed`.

#### Number of heat transfer units vector, NTU

$M$ -element vector of NTU values at which to specify the effectiveness tabular data. The number of transfer units (NTU) is a dimensionless parameter defined as

$$NTU = \frac{A_s U}{C_{min}}$$

where:

- $A_S$  is the heat transfer surface area.
- $U$  is the overall heat transfer coefficient.
- $C_{\min}$  is the smallest of the thermal capacity rates for the hot and cold fluids.

This parameter is visible only when the **Flow Arrangement** parameter is set to `Generic – effectiveness` table. The default vector is [0.5, 1.0, 2.0, 3.0, 4.0].

### Thermal capacity ratio vector, CR

$N$ -element vector of thermal capacity ratios at which to specify the effectiveness tabular data. The thermal capacity ratio is the fraction

$$C_r = \frac{C_{\min}}{C_{\max}},$$

where  $C_{\min}$  and  $C_{\max}$  are the minimum and maximum thermal capacity rates. This parameter is visible only when the **Flow arrangement** parameter is set to `Generic – effectiveness` table. The default vector is [0.0, 0.25, 0.5, 0.75, 1.0].

### Effectiveness table, E(NTU, CR)

$M$ -by- $N$  matrix with the heat exchanger effectiveness values. The matrix rows correspond to the different values specified in the **Number of heat transfer units vector, NTU** parameter. The matrix columns correspond to the values specified in the **Thermal capacity ratio vector, CR** parameter.

This parameter is visible only when the **Flow arrangement** parameter is set to `Generic – effectiveness` table. The default table is a 6-by-5 matrix ranging in value from 0.30 to 0.99.

### Wall thermal resistance

Thermal resistance of the interface wall separating the two heat exchanger fluids. The block uses this parameter to compute the rate of heat transfer between the fluids. The default value is  $1.6 \times 10^{-4}$  k/W.

### Controlled Fluid 1 Tab | Controlled Fluid 2 Tab

#### Heat transfer surface area

Aggregate surface area for heat transfer between the cold and hot fluids. The default value is  $0.01 \text{ m}^2$ .

#### Fouling factor

Empirical parameter used to quantify the increased thermal resistance due to dirt deposits on the heat transfer surface. The default value is  $1 \times 10^{-4} \text{ m}^2 \cdot \text{K}/\text{W}$ .

#### Minimum fluid-wall heat transfer coefficient

Smallest allowed value of the heat transfer coefficient. The heat transfer coefficients specified through physical signal ports HC1 and HC2 saturate at this value. The default value is  $5 \text{ W}/(\text{m}^2 \cdot \text{K})$ .

The block uses the heat transfer coefficient to calculate the heat transfer rate between fluids 1 and 2 as described in “Heat Transfer Rate” on page 1-762.

## Version History

Introduced in R2016a

## References

- [1] Holman, J. P. *Heat Transfer*. 9th ed. New York, NY: McGraw Hill, 2002.
- [2] Shah, R. K. and D. P. Sekulic. *Fundamentals of Heat Exchanger Design*. Hoboken, NJ: John Wiley & Sons, 2003.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Heat Exchanger Interface (TL) | Heat Exchanger Interface (G)

## Fan (G)

Fan in gas network

**Library:** Simscape / Fluids / Gas / Turbomachinery



### Description

The Fan (G) block represents a fan in a gas network. You can model the torque and pressure gain over the fan as a function of static pressure and flow rate or by using 1D or 2D tabulated reference pressure, shaft speed, and flow rate data.

By default, flow and pressure gain are from port **A** to port **B**. Port **C** represents the fan casing, and port **R** represents the fan shaft. You can specify the normal operating shaft direction in the **Mechanical orientation** parameter. If the shaft begins to spin in the opposite direction, the pressure difference across the fan drops to zero.

### Parameterization by Nominal Pressure, Flow Rate, and Shaft Speed

When you set the **Fan parameterization** parameter to **Static pressure and flow rate at reference shaft speed**, the block uses the analytical fan affinity laws and reference pressure differential to calculate the pressure gain from port **A** to port **B**:

$$p_B - p_A = \Delta p_{ref} \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2,$$

where:

- $\Delta p_{ref}$  is the reference pressure differential. The block uses a quadratic fit of the fan pressure differential values at the **Maximum static pressure gain at zero flow**, **Nominal static pressure gain**, and **Maximum volumetric flow rate at zero pressure** parameters.
- $\omega$  is the shaft angular velocity,  $\omega_R - \omega_C$ .
- $\omega_{ref}$  is the **Reference shaft speed** parameter.
- $\frac{D}{D_{ref}}$  is the **Fan diameter scale factor** parameter.

The block calculates the shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \Phi_{ref} \frac{\omega^2}{\omega_{ref}^3} \left( \frac{D}{D_{ref}} \right)^5.$$

Where  $\Phi_{ref}$  is the proportion of the pressure gain to the fan efficiency:

$$\Phi_{ref} = \frac{q_{ref} \Delta p_{ref}}{\eta_{ref}}.$$

When you set the **Shaft power specification** parameter to **Fan efficiency**, the block uses a quadratic fit of efficiency between the fan peak performance,  $\eta_{nom}$ , and 0.  $\eta_{nom}$  is equivalent to the **Nominal efficiency** parameter, which the block interprets as the peak efficiency. If you set the **Shaft power specification** parameter to **Brake power**, the block derives the nominal fan efficiency from the nominal brake power,  $\Phi_{nom}$ , at peak or nominal conditions:

$$\eta_{nom} = \frac{q_{nom}\Delta p_{nom}}{\Phi_{nom}}.$$

The block assumes the efficiency is zero when there is no flow or when the flow reaches the maximum volumetric flow rate at zero pressure. The block uses the current flow  $q$  to compute the reference flow rate as:

$$q_{ref} = q \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

### 1-D Tabulated Data Parameterization: Pressure as a Function of Flow Rate at Reference Shaft Speed

When you set the **Fan parameterization** parameter to **1D tabulated data - static pressure vs. flow rate at reference shaft speed**, you can model fan performance as a function of volumetric flow rate. The block interpolates the pressure gain from port **A** to port **B** from the **1-D Static pressure gain vector** parameter,  $\Delta p_{ref}(q_{ref})$ :

$$p_B - p_A = \Delta p_{ref}(q_{ref}) \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2.$$

Here,  $\rho$  is the moist air density, and  $\rho_{ref}$  is the reference density, which is equivalent to the **Reference density** parameter. The block calculates the shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \Phi_{ref}(q_{ref}) \frac{\omega^2}{\omega_{ref}^3} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where  $\rho_{ref}$  is the **Reference density**.

The block uses the current flow  $q$  to compute the reference flow rate:

$$q_{ref} = q \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### 2-D Tabulated Data Parameterization: Pressure as a Function of Shaft Speed and Flow Rate

When you set the **Fan parameterization** parameter to **2D tabulated data - static pressure vs. shaft speed and flow rate**, you can model fan performance as a 2-D function of volumetric flow rate and angular velocity. The block interpolates the pressure gain from port **A** to port **B** from the **2-D Static pressure gain table, dp(w,q)** parameter. The block defines the reference pressure gain,  $\Delta p_{ref}(q_{ref}, \omega)$ , as

$$p_B - p_A = \Delta p_{ref}(q_{ref}, \omega) \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^2.$$

The block calculates shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \frac{\Phi_{ref}(q_{ref}, \omega)}{\omega} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where the reference mechanical power is a function of the reference flow rate and the current shaft speed.

The block uses the current flow  $q$  to compute the reference flow rate:

$$q_{ref} = q \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### Missing Data

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table, dp(w,q)**, **Efficiency table, eta(w,q)**, and **Mechanical power table, W(w,q)** parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### 2-D Tabulated Data Parameterization: Flow Rate as a Function of Shaft Speed and Pressure

When you set the **Fan parameterization** parameter to 2D tabulated data - flow rate vs. shaft speed and static pressure, you can model the flow rate through the fan as a 2-D function of pressure and angular velocity. The volumetric flow rate is interpolated from the 2-D **Volumetric flow rate table, q(w,dp)** parameter,  $q_{ref}$ . The reference flow rate is a function of the reference pressure gain,  $\Delta p_{ref}$ , and the current shaft speed,  $\omega$ :

$$q = q_{ref}(\Delta p_{ref}, \omega) \left( \frac{D}{D_{ref}} \right)^3,$$

where the reference pressure gain derives from the pressure differential over the fan:

$$\Delta p_{ref} = (p_B - p_A) \left( \frac{\rho_{ref}}{\rho} \right) \left( \frac{D_{ref}}{D} \right)^2.$$

The shaft torque derives from the reference mechanical power and the fan affinity laws:

$$\tau = \frac{\Phi_{ref}(\Delta p_{ref}, \omega)}{\omega} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where the reference mechanical power is a function of the reference flow rate and the current shaft speed.



When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### Missing Data

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w,dp)$ , Efficiency table,  $\eta(w,dp)$ , and Mechanical power table,  $W(w,dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### Power and Efficiency

You can specify shaft power as either fan efficiency or brake power.

The block calculates efficiency as

$$\eta = \frac{\Phi_{fluid}}{\Phi_{brake}},$$

where the *brake power*, or mechanical power measured at the shaft, is

$$\Phi_{brake} = \tau\omega.$$

The block calculates fluid power as

$$\Phi_{fluid} = q(p_B - p_A).$$

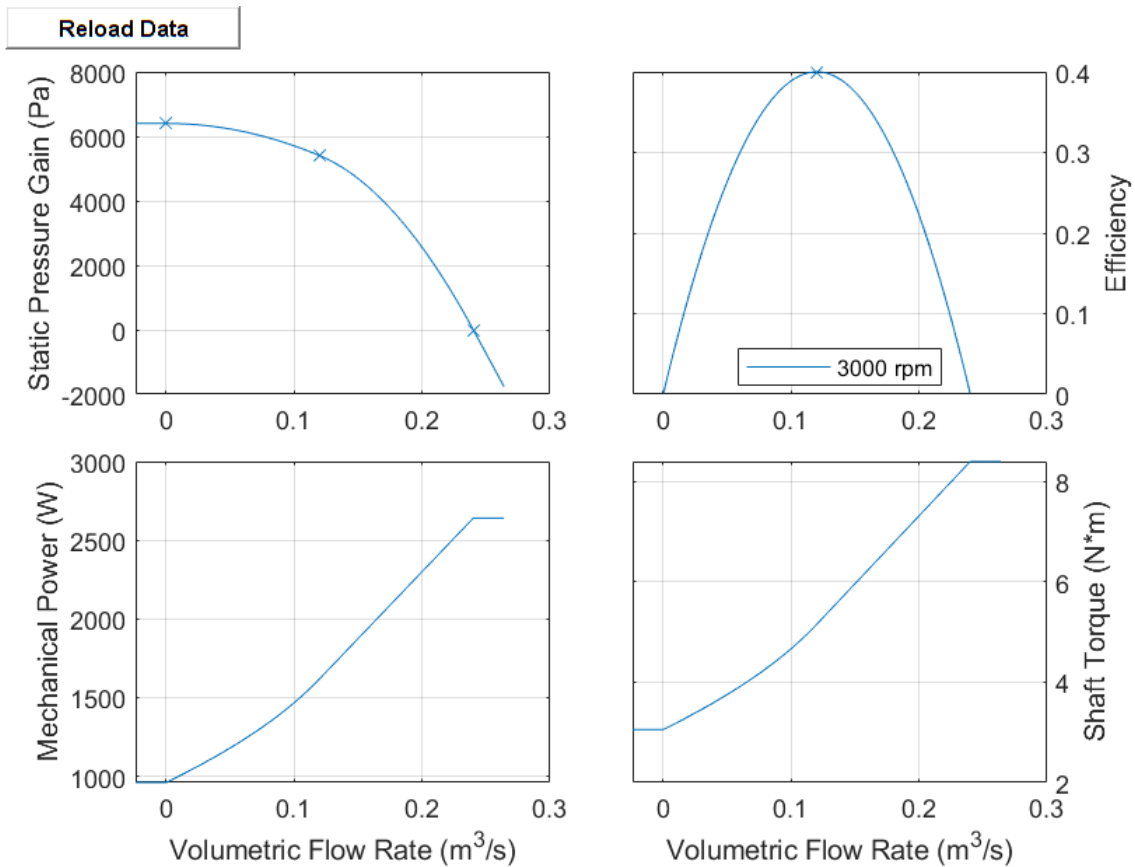
The block calculates torque as

$$\tau = \frac{\Phi_{brake}}{\omega}.$$

### Visualizing the Fan Curve

You can check the parameterized fan performance by plotting the pressure, power, efficiency, and torque as a function of the flow. To generate a plot of the current fan settings, right-click on the block and select **Fluids > Plot Fan Characteristics**. If you change settings or data, click **Apply** on the block parameters and click **Reload Data** on the fan curve figure.

The default block parameterization results in these plots:



### Assumptions and Limitations

- If the shaft rotates opposite to the specified mechanical orientation, pressure difference across the block drops to zero and the results may not be accurate.
- The block assumes that the fan is quasi-steady.
- The block simulates fan performance in terms of static pressure rise, and not total fan pressure.

### Ports

#### Conserving

##### A – Fluid entry

gas

Gas conserving port associated with the fluid.

##### B – Fluid exit

gas

Gas conserving port associated with the fluid.

##### R – Shaft

mechanical rotational

Mechanical rotational conserving port associated with the shaft.

### **C – Casing**

mechanical rotational

Mechanical rotational conserving port associated with the casing.

## **Parameters**

### **Fan parameterization – Fan performance model**

Static pressure and flow rate at reference shaft speed (default) | 1D tabulated data - static pressure vs. flow rate at reference shaft speed | 2D tabulated data - static pressure vs. shaft speed and flow rate | 2D tabulated data - flow rate vs. shaft speed and static pressure

Fan performance model, specified as:

- **Static pressure and flow rate at reference shaft speed:** Specify fan performance based on typical, nominal, or rated pressure gain and volumetric flow rate.
- **1D tabulated data – static pressure vs flow rate at reference shaft speed:** Specify fan performance based on interpolation of pressure gain data as a function of volumetric flow rate.
- **2D tabulated data – static pressure vs shaft speed and flow rate:** Specify fan performance based on the interpolation of pressure gain data as a function of shaft speed and volumetric flow rate.
- **2D tabulated data – flow rate vs shaft speed and static pressure:** Specify fan performance based on the interpolation of volumetric flow rate data as a function of shaft speed and pressure gain.

### **Shaft power specification – Power definition**

Fan efficiency (default) | Brake power

Fan power specification, specified as:

- **Fan efficiency:** Derive the mechanical power from the fan efficiency.
- **Mechanical power:** Specify the mechanical power directly.

### **Nominal volumetric flow rate – Flow rate at reference shaft speed**

0.12 m<sup>3</sup>/s (default) | positive scalar

Volumetric flow rate through the fan at the reference shaft speed under nominal, typical, or rated operating conditions.

### **Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

### **Nominal static pressure gain – Pressure gain at reference shaft speed**

5400 Pa (default) | positive scalar

Pressure increase from port **A** to port **B** at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Nominal efficiency — Efficiency at reference shaft speed**

0.40 (default) | positive scalar

Efficiency of converting the shaft power to fluid power at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set:

- **Fan parameterization** to Static pressure and flow rate at reference shaft speed.
- **Shaft power specification** to Fan efficiency.

**Nominal mechanical power — Power at nominal efficiency**

1620 W (default) | positive scalar

Mechanical power driving moist air flow at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set:

- **Fan parameterization** to Static pressure and flow rate at reference shaft speed.
- **Shaft power specification** to Brake power.

**Maximum static pressure gain at zero flow — Maximum pressure at reference shaft speed**

6400 Pa (default) | positive scalar

Pressure increase from port **A** to port **B** at the reference shaft speed when there is no flow through the fan.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Maximum volumetric flow rate at zero pressure — Maximum flow rate at reference shaft speed**

0.24 m<sup>3</sup>/s (default) | positive scalar

Free-delivery volumetric flow rate at the reference shaft speed and constant pressure.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Reference shaft speed — Fan curve reference speed**

3000 rpm (default) | positive scalar

Reference shaft angular velocity corresponding to the fan characteristic curve data.

#### Dependencies

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed or 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Volumetric flow rate vector — Fan curve flow rate vector

[.0278, .0556, .0833, .111, .139, .167] m<sup>3</sup>/s (default) | vector

Vector of volumetric flow rate grid points for the 1-D interpolation of the fan characteristic curve. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Static pressure gain vector — Pressure gain for given volumetric flow rate

[6410, 6375, 6018, 5366, 4501, 3609] Pa (default) | vector

Vector of pressure gain data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The pressure gain is the increase in pressure from port **A** to port **B** at the reference shaft speed. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Efficiency vector — Efficiency for given volumetric flow rate

[.257, .394, .453, .47, .459, .415] (default) | vector

Vector of fan efficiency data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The efficiency is the ratio of fluid power to shaft mechanical power at the reference shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed and **Shaft power specification** to Fan efficiency.

#### Mechanical power vector — Power for parameterization of torque

[693, 900, 1107, 1267, 1363, 1452] W (default) | 1-by-n vector

Vector of shaft mechanical power data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The mechanical power is the power that drives the fan at the reference shaft speed. These values can be negative if the fan data extends beyond the normal operating region.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed and **Shaft power specification** to Brake power.

**Reference density – Density associated with fan curve data**

1.2 kg/m<sup>3</sup> (default) | positive scalar

Moist air density for a given characteristic fan curve.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed, 2D tabulated data - static pressure vs. shaft speed and flow rate or 2D tabulated data - flow rate vs. shaft speed and static pressure.

**Shaft speed vector,  $w$  – Shaft angular velocity for given**

[2400; 3000; 3600] rpm (default) | vector

Vector of shaft angular velocity grid points for the 2-D interpolation of the fan characteristic curves.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate or 2D tabulated data - flow rate vs. shaft speed and static pressure.

**Volumetric flow rate vector,  $q$  – Flow rate for parameterization of pressure gain**

[.0278, .0556, .0833, .111, .139, .167] m<sup>3</sup>/s (default) | 1-by- $n$  vector

Vector of volumetric flow rate grid points for the 2-D interpolation of the fan characteristic curves. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate.

**Static pressure gain table,  $dp(w,q)$  – Pressure for parameterization of pressure**

[4111, 4010, 3551, 2881, 2167, 1453; 6410, 6375, 6018, 5366, 4501, 3609; 9217, 9285, 9022, 8428, 7552, 6482] Pa (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of pressure gain data points for the 2-D interpolation of the pressure gain. The pressure gain is the increase in pressure from port **A** to port **B**. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- $N$  is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial

numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate.

#### Efficiency table, $eta(w,q)$ – Efficiency for parameterization of torque

[.3, .434, .468, .459, .4, .3; .257, .394, .453, .47, .459, .415; .225, .359, .434, .461, .47, .459] 1 (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of efficiency data points for the 2-D interpolation of torque. The efficiency is the ratio of fluid power to shaft mechanical power. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter.
- *N* is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate and **Shaft power specification** to Fan efficiency.

#### Mechanical power table, $W(w,q)$ – Mechanical power for parameterization of torque

[381, 514, 632, 697, 753, 809; 693, 900, 1107, 1267, 1363, 1452; 1139, 1438, 1732, 2029, 2233, 2358] W (default) | *M*-by-*N* matrix

*M*-by-*N* table of mechanical power data points for the 2-D interpolation of torque. These values can be negative if the fan data extends beyond the normal operating region. The mechanical power is the power that drives the fan. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- *N* is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $\eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate and **Shaft power specification** to Brake power.

#### Static pressure gain vector, $dp$ — Pressure for parameterization of flow rate

[31, 62, 93, 124] Pa (default) | 1-by- $N$  vector

Vector of pressure gain grid points for the 2-D interpolation of the fan characteristic curves. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure.

#### Volumetric flow rate table, $q(w,dp)$ — Flow rate for parameterization of flow rate

[.802, .759, .703, .611; .936, .902, .862, .81; 1.056, 1.027, .994, .956]  $m^3/s$  (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rate data points for the 2-D interpolation of volumetric flow rate. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- $N$  is the number of elements in the **Static pressure gain vector,  $Dp$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w,dp)$** , **Efficiency table,  $\eta(w,dp)$** , and **Mechanical power table,  $W(w,dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.



### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure.

### Efficiency table, $\eta(w, dp)$ — Efficiency for parameterization of torque

[.088, .162, .22, .261; .068, .128, .18, .222; .055, .105, .148, .188] (default)  
| *M*-by-*N* matrix

*M*-by-*N* matrix of efficiency data points for the 2-D interpolation of torque. The efficiency is the ratio of fluid power to shaft mechanical power. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector, *w*** parameter.
- *N* is the number of elements in the **Static pressure gain vector, *Dp*** parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w, dp)$** , **Efficiency table,  $\eta(w, dp)$** , and **Mechanical power table,  $W(w, dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure and **Shaft power specification** to Fan efficiency.

### Mechanical power table, $W(w, dp)$ — Mechanical power for parameterization of torque

[283, 290, 297, 290; 427, 437, 445, 452; 595, 606, 625, 631] W (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mechanical power data points for the 2-D interpolation of torque. These values can be negative if the fan data extends beyond the normal operating region. The mechanical power is the power that drives the fan. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector, *w*** parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- *N* is the number of elements in the **Static pressure gain vector, *Dp*** parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w, dp)$** , **Efficiency table,  $\eta(w, dp)$** , and **Mechanical power table,  $W(w, dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure and **Shaft power specification** to Brake power.

### Fan diameter scale factor — Model-to-reference scale factor

1 (default) | positive scalar

Geometric scale factor to increase or decrease the size of the simulated fan from the given fan parameterization. The scaling may not be accurate for scale factors much larger or much smaller than 1.

### Mechanical orientation — Rotational orientation

Positive angular velocity of port R relative to port C corresponds to normal fan operation (default) | Negative angular velocity of port R relative to port C corresponds to normal fan operation

Normal operating shaft direction. By default, flow and pressure gain are from port **A** to port **B**.

### Inlet flow area (port A) — Port A area

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the moist air flow at the fan inlet.

### Outlet flow area (port B) — Port B area

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the moist air flow at the fan outlet.

## Version History

### Introduced in R2018b

#### Extend performance beyond normal operating conditions

Both the 1-D and 2-D parameterizations now allow negative values. When simulation is outside the range of the provided table, block extrapolates the pressure based on the average slope of the fan curves.

You can now use NaN elements where data is unavailable. These 2-D tabulated fan parameters support contiguous NaN elements in the upper-right portion of the table:

- **Static pressure gain table, dp(w,q)**
- **Efficiency table, eta(w,q)**
- **Mechanical power table, W(w,q)**
- **Volumetric flow rate table, q(w,dp)**
- **Efficiency table, eta(w,dp)**
- **Mechanical power table, W(w,dp)**

For each block, if the shaft rotates opposite to the specified mechanical orientation, the pressure difference across the block drops to zero and the results may not be accurate.

## 2-D Tabulated Data Parameterization: Flow Rate as a Function of Shaft Speed and Pressure Ratio

*Not recommended starting in R2021b*

In R2021b, the block no longer supports the 2-D Tabulated Data Parameterization: Flow Rate as a Function of Shaft Speed and Pressure Ratio parameterization. In R2021b and later, if you open models created in a prior release that include the Fan (G) block, Simscape Fluids replaces the block with the Fan (MA) - Legacy block. This block supports the 2-D Tabulated Data Parameterization: Flow Rate as a Function of Shaft Speed and Pressure Ratio setting.

You can preserve the functionality of a model using this parameterization by setting **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure<sup>1</sup> and converting the ratios to absolute values. An example script that performs this conversion takes in the legacy parameters `omega_DpMax_TLU`, `DpMax_TLU`, `omega_flow_TLU`, `Dp_DpMax_TLU`, `flow_rate_TLU`, and `eta_flow_TLU` and returns the converted parameters `omega_g_TLU`, `pressure_g_TLU`, `pressure_g_TLU`, and `eta_g_TLU`:

```
% Shaft speed vector for maximum pressure rise vector
omega_DpMax_TLU = [1800, 2400, 3000];

% Maximum pressure rise vector
DpMax_TLU       = [400, 1200, 2000];

% Shaft speed vector, omega
omega_flow_TLU  = [1800, 2400, 3000];

% Static pressure rise ratio vector, Dp/DpMax
Dp_DpMax_TLU   = linspace(0, 1, 4);

% Flow rate table, q(omega,Dp/DpMax)
flow_rate_TLU  = [
    0.33    0.26    0.18    0.07
    1.20    0.91    0.64    0.26
    1.84    1.61    1.13    0.46];

% Total efficiency table, Eta(omega,Dp/DpMax)
eta_flow_TLU   = [
    0.22    0.25    0.27    0.28
    0.48    0.52    0.55    0.53
    0.42    0.45    0.49    0.44];

% Create interpolants of the tables
DpMax_TLU_interp = griddedInterpolant(omega_DpMax_TLU, DpMax_TLU, ...
    'linear', 'linear');

flow_rate_TLU_interp = griddedInterpolant({omega_flow_TLU, Dp_DpMax_TLU}, flow_rate_TLU, ...
    'linear', 'linear');

eta_flow_TLU_interp = griddedInterpolant({omega_flow_TLU, Dp_DpMax_TLU}, eta_flow_TLU, ...
    'linear', 'nearest');

% Maximum pressure rise
DpMax = DpMax_TLU_interp(max(omega_flow_TLU, omega_DpMax_TLU(1)));
```

<sup>1</sup> Prior to R2021b, this setting was called 2D tabulated data - flow rate and total efficiency vs. angular speed and static pressure.

```
% Shaft speed vector, w
omega_q_TLU = omega_flow_TLU;

% Static pressure gain vector, Dp
pressure_q_TLU = unique(DpMax(:)*Dp_DpMax_TLU(:)');

% Interpolation query points as full grid arrays
omega_grid = omega_q_TLU(:)*ones(1, length(pressure_q_TLU));

Dp_DpMax_grid = pressure_q_TLU(:)' ./ DpMax(:);

% Volumetric flow rate table, q(w,Dp)
flow_rate_q_TLU = flow_rate_TLU_interp(omega_grid, Dp_DpMax_grid);

flow_rate_q_TLU = max(flow_rate_q_TLU, 1e-4*flow_rate_TLU(1,1)); % keep it > 0

% Efficiency table, eta(w,Dp)
eta_q_TLU = eta_flow_TLU_interp(omega_grid, Dp_DpMax_grid);
```

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Compressor (G) | Turbine (G)

## Fixed Orifice

Hydraulic orifice with constant cross-sectional area

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Orifices



### Description

The Fixed Orifice block models a sharp-edged constant-area orifice, flow rate through which is proportional to the pressure differential across the orifice. The flow rate is determined according to the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$\Delta p = p_A - p_B,$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A$	Orifice passage area
$\rho$	Fluid density
$p_{cr}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{cr}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = (p_{avg} + p_{atm})(2 - B_{lam})$$

$$p_{avg} = (p_A + p_B)/2$$

where

$p_{avg}$	Average pressure between the block terminals
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Orifice hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ .

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- Fluid inertia is not taken into account.

### Ports

#### Conserving

##### A – Hydraulic conserving port associated with the orifice inlet

hydraulic

Hydraulic conserving port associated with the orifice inlet.

##### B – Hydraulic conserving port associated with the orifice outlet

hydraulic

Hydraulic conserving port associated with the orifice outlet.

### Parameters

#### Orifice area – Orifice passage area

1e-4 m<sup>2</sup> (default) | positive scalar

Orifice passage area.

### Flow discharge coefficient — Semi-empirical parameter for orifice capacity characterization

0.7 (default) | positive scalar

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets.

### Laminar transition specification — Select how block transitions between the laminar and turbulent regimes

Pressure ratio (default) | Reynolds number

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes

0.999 (default) | positive scalar in the range of (0,1)

Pressure ratio at which the flow transitions between laminar and turbulent regimes.

#### Dependencies

To enable this parameter, set **Laminar transition specification** to **Pressure ratio**.

### Critical Reynolds number — Maximum Reynolds number for laminar flow

12 (default) | positive scalar

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges.

#### Dependencies

To enable this parameter, set **Laminar transition specification** to **Reynolds number**.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Annular Orifice | Constant Area Hydraulic Orifice | Fixed Orifice Empirical | Fixed Orifice with Fluid Inertia | Orifice with Variable Area Round Holes | Orifice with Variable Area Slot | Variable Area Hydraulic Orifice | Variable Orifice

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”



# Fixed Orifice Empirical

Fixed hydraulic orifice based on empirical data



## Library

Orifices

## Description

The Fixed Orifice Empirical block models a fixed orifice in hydraulic systems with data obtained from experimental testing. The data required for characterization is the set of pressure differentials across the orifice, together with associated flow rates determined for a particular fluid and temperature.

The flow rate through the orifice is determined with the table lookup block from the set of experimental measurements

$$q = f(p)$$

where

$q$	Volumetric flow rate
$p$	Pressure differential

You can select from two interpolation and two extrapolation methods.

---

**Note** Extrapolation could result in large errors if the operating point deviates significantly from the area of experiments.

---

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ .

## Parameters

### Tabulated pressure differentials

Specify the pressure differential vector as a one-dimensional array. The vector contains values of pressure differentials obtained during experimental characterization of the orifice. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in bar, are [-40.0, -30.0, -20.0, -10.0, -5.0, 0.0, 5.0, 10.0, 20.0, 30.0, 40.0].

### Tabulated flow rates

Specify the vector of flow rates through the orifice, corresponding to these pressure differentials, as a one-dimensional array. The vector must be of the same size as the **Tabulated pressure**

**differentials** vector. The default values, in  $\text{m}^3/\text{s}$ , are [ -0.0024436 -0.0021248 -0.0016852 -0.0012248 -8.4476e-4 0 8.5333e-4 0.0012068 0.0017067 0.0020902 0.0024136 ].

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

### Extrapolation method

Use extrapolation with extreme caution, because moving beyond the measurement limits could result in large errors. Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

## Version History

Introduced in R2012b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Fixed Orifice | Fixed Orifice with Fluid Inertia

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Fixed Orifice with Fluid Inertia

Fixed hydraulic orifice accounting for flow inertia



### Library

Orifices

### Description

The Fixed Orifice with Fluid Inertia block models a hydraulic fixed orifice and accounts for the fluid inertia, in addition to the static pressure loss.

Fluid inertia plays a noticeable role in orifices with a large ratio of orifice length to the orifice hydraulic diameter ( $L / D_H$ ) and in sharp-edged short orifices when the rate of change of flow rate (fluid acceleration) is relatively large.

The orifice is based on the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p_r}{(p_r^2 + p_{cr}^2)^{1/4}}$$

$$p = p_{in} + p_r$$

$$p_{in} = \rho \frac{L}{A} \frac{dq}{dt}$$

where

$q$	Volumetric flow rate
$p$	Total pressure differential
$p_{in}$	Inertial pressure drop
$p_r$	Resistive pressure drop
$C_D$	Flow discharge coefficient
$A$	Orifice passage area
$L$	Orifice length
$\rho$	Fluid density
$p_{cr}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{cr}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = (p_{avg} + p_{atm})(1 - B_{lam})$$

$$p_{avg} = (p_A + p_B)/2$$

where

$p_{avg}$	Average pressure between the block terminals
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\Pi}}$$

where

$D_H$	Orifice hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

Connections A and B are conserving hydraulic ports associated with the orifice inlet and outlet, respectively. The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ .

## Parameters

### Orifice area

Cross-sectional area of the orifice. The default value is  $1e-4 \text{ m}^2$ .

### Orifice length

Total length of the orifice. Generally, increase the geometrical length of the orifice up to  $2 \cdot 0.8 \cdot D_H$  (where  $D_H$  is the orifice hydraulic diameter) to take into account the added volumes of fluid on both sides of the orifice. The default value is  $0.01 \text{ m}$ .

### Flow discharge coefficient

Semi-empirical parameter for orifice capacity characterization. The coefficient affects the resistive pressure drop in the orifice. The default value is  $0.6$ .

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.

- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### **Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### **Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 10. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

### **Initial flow rate**

Flow rate through the orifice at the start of simulation. This parameter specifies the initial condition for use in computing the block's state at the beginning of a simulation run. For more information, see “Initial Conditions Computation”. The default value is 0.

## **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

## **Version History**

**Introduced in R2013a**

## **See Also**

Fixed Orifice | Fixed Orifice Empirical

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Fixed-Displacement Motor

Hydraulic-to-mechanical power conversion device

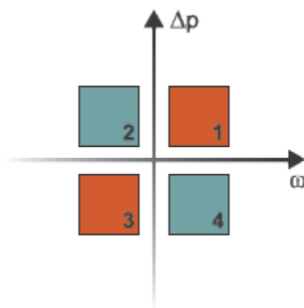
**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Fixed-Displacement Motor block represents a device that extracts power from a hydraulic (isothermal liquid) network and delivers it to a mechanical rotational network. The motor displacement is fixed at a constant value that you specify through the **Displacement** parameter.

Ports **A** and **B** represent the motor inlet and outlet, respectively. Port **S** represents the motor drive shaft. During normal operation, the angular velocity at port **S** is positive if the pressure drop from port **A** to port **B** is positive also. This operation mode is referred to here as forward motor.



## Operation Modes

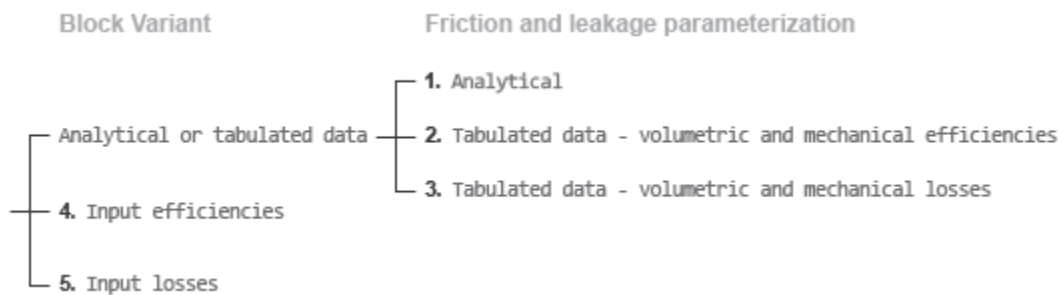
A total of four operation modes are possible. The working mode depends on the pressure drop from port **A** to port **B** ( $\Delta p$ ) and on the angular velocity at port **S** ( $\omega$ ). The “Operation Modes” on page 1-793 figure maps the modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart. The modes are labeled 1-4:

- Mode **1**: forward motor — A positive pressure drop generates a positive shaft angular velocity.
- Mode **2**: reverse pump — A negative shaft angular velocity generates a negative pressure gain (shown in the figure as a positive pressure drop).
- Mode **3**: reverse motor — A negative pressure drop generates a negative shaft angular velocity.
- Mode **4**: forward pump — A positive shaft angular velocity generates a positive pressure gain (shown in the figure as a negative pressure drop).

The response time of the motor is considered negligible in comparison with the system response time. The motor is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.

## Block Variants and Loss Parameterizations

The motor model accounts for power losses due to leakage and friction. Leakage is internal and occurs between the motor inlet and outlet only. The block computes the leakage flow rate and friction torque using your choice of five loss parameterizations. You select a parameterization using block variants and, in the Analytical or tabulated data case, the **Leakage and friction parameterization** parameter.



## Loss Parameterizations

The block provides three Simscape variants to select from. To change the active block variant, use the **Modeling option** parameter. The available variants are:

- **Analytical or tabulated data** — Obtain the mechanical and volumetric efficiencies or losses from analytical models based on nominal parameters or from tabulated data. Use the **Leakage and friction parameterization** parameter to select the exact input type.
- **Input efficiencies** — Provide the mechanical and volumetric efficiencies directly through physical signal input ports.
- **Input losses** — Provide the mechanical and volumetric losses directly through physical signal input ports. The mechanical loss is defined as the internal friction torque. The volumetric loss is defined as the internal leakage flow rate.

## Flow Rate and Driving Torque

The volumetric flow rate required to power the motor is

$$q = q_{\text{Ideal}} + q_{\text{Leak}}$$

where:

- $q$  is the net volumetric flow rate.
- $q_{\text{Ideal}}$  is the ideal volumetric flow rate.
- $q_{\text{Leak}}$  is the internal leakage volumetric flow rate.

The torque generated at the motor is

$$\tau = \tau_{\text{Ideal}} - \tau_{\text{Friction}}$$

where:

- $\tau$  is the net torque.



- $\tau_{\text{Ideal}}$  is the ideal torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal volumetric flow rate is

$$q_{\text{Ideal}} = D\omega,$$

and the ideal generated torque is

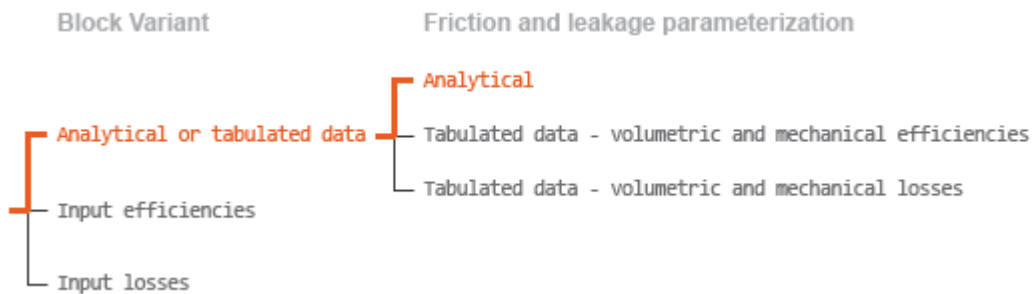
$$\tau_{\text{Ideal}} = D\Delta p,$$

where:

- $D$  is the specified value of the **Displacement** block parameter.
- $\omega$  is the instantaneous angular velocity of the rotary shaft.
- $\Delta p$  is the instantaneous pressure drop from inlet to outlet.

### Leakage Flow Rate and Friction Torque

The internal leakage flow rate and friction torque calculations depend on the block variant selected. If the block variant is **Analytical** or **tabulated data**, the calculations depend also on the **Leakage and friction parameterization** parameter setting. There are five possible permutations of block variant and parameterization settings.



### Case 1: Analytical Efficiency Calculation

If the active block variant is **Analytical** or **tabulated data** and the **Leakage and friction parameterization** parameter is set to **Analytical**, the leakage flow rate is

$$q_{\text{Leak}} = K_{\text{HP}}\Delta p,$$

and the friction torque is

$$\tau_{\text{Friction}} = (\tau_0 + K_{\text{TP}}|\Delta p|)\tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.

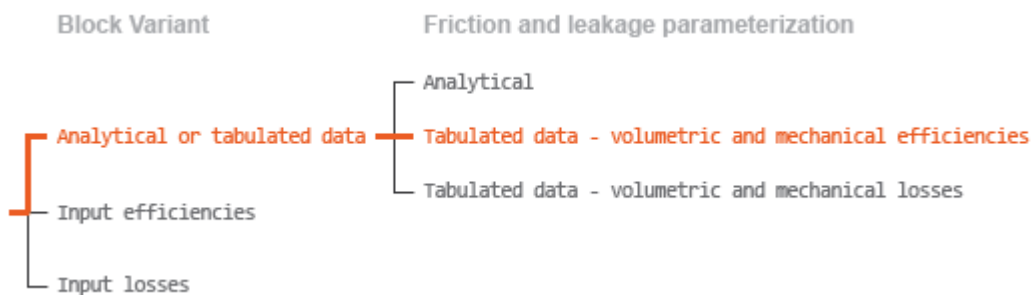
- $K_{TP}$  is the specified value of the **Friction torque vs pressure drop coefficient** block parameter.
- $\tau_0$  is the specified value of the **No-load torque** block parameter.
- $\omega_{Threshold}$  is the threshold angular velocity for the motor-pump transition. The threshold angular velocity is an internally set fraction of the specified value of the **Nominal shaft angular velocity** block parameter.

The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{HP} = \frac{\nu_{Nom} \rho_{Nom} \omega_{Nom} D_{Max}}{\rho v \Delta p_{Nom}} \left( \frac{1}{\eta_{v,Nom}} - 1 \right),$$

where:

- $\nu_{Nom}$  is the specified value of the **Nominal kinematic viscosity** block parameter. This is the kinematic viscosity at which the nominal volumetric efficiency is specified.
- $\rho_{Nom}$  is the specified value of the **Nominal fluid density** block parameter. This is the density at which the nominal volumetric efficiency is specified.
- $\omega_{Nom}$  is the specified value of the **Nominal shaft angular velocity** block parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.
- $\rho$  is the actual fluid density in the attached hydraulic (isothermal liquid) network. This density can differ from the specified value of the **Nominal fluid density** block parameter.
- $v$  is the kinematic viscosity of the fluid associated with the fluid network.
- $\Delta p_{Nom}$  is the specified value of the **Nominal pressure drop** block parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.
- $\eta_{v,Nom}$  is the specified value of the **Volumetric efficiency at nominal conditions** block parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.



### Case 2: Efficiency Tabulated Data

If the active block variant is **Analytical** or **tabulated data** and the **Leakage and friction parameterization** parameter is set to **Tabulated data – volumetric and mechanical efficiencies**, the leakage flow rate is

$$q_{Leak} = q_{Leak, Motor} \frac{(1 + \alpha)}{2} + q_{Leak, Pump} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{Friction} = \tau_{Friction, Motor} \frac{1 + \alpha}{2} + \tau_{Friction, Pump} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $q_{\text{Leak, Motor}}$  is the leakage flow rate in motor mode.
- $q_{\text{Leak, Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction, Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction, Pump}}$  is the friction torque in pump mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure drop threshold for motor-pump transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.

The leakage flow rate is computed from efficiency tabulated data through the equation

$$q_{\text{Leak, Motor}} = (1 - \eta_v)q,$$

in motor mode and through the equation

$$q_{\text{Leak, Pump}} = -(1 - \eta_v)q_{\text{Ideal}}.$$

in pump mode, where:

- $\eta_v$  is the volumetric efficiency obtained through interpolation or extrapolation of the **Volumetric efficiency table, e\_v(dp,w)** parameter data.

Similarly, the friction torque is computed from efficiency tabulated data through the equation

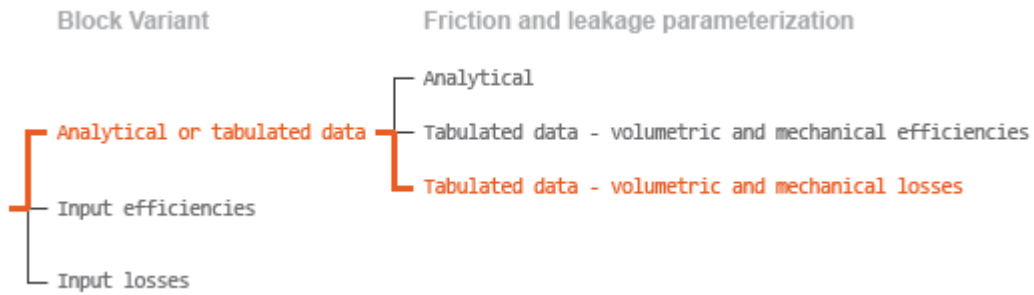
$$\tau_{\text{Friction, Motor}} = (1 - \eta_m)\tau_{\text{Ideal}},$$

in motor mode and through the equation

$$\tau_{\text{Friction, Pump}} = -(1 - \eta_m)\tau.$$

in pump mode, where:

- $\eta_m$  is the mechanical efficiency obtained through interpolation or extrapolation of the **Mechanical efficiency table, e\_m(dp,w)** parameter data.



**Case 3: Loss Tabulated Data**

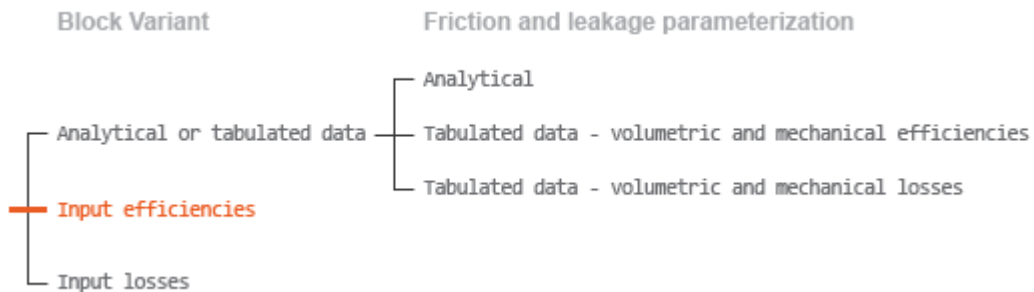
If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses, the leakage flow rate equation is

$$q_{Leak} = q_{Leak}(\Delta p, \omega).$$

and the friction torque equation is

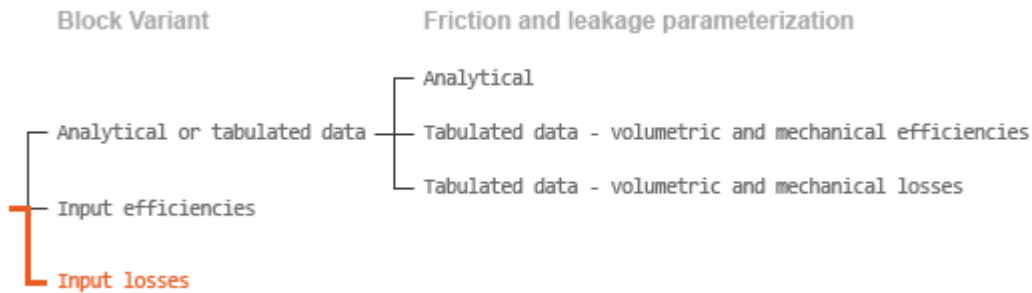
$$\tau_{Friction} = \tau_{Friction}(\Delta p, \omega),$$

where  $q_{Leak}(\Delta p, \omega)$  and  $\tau_{Friction}(\Delta p, \omega)$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the **Volumetric loss table, q\_loss(dp,w)** and **Mechanical loss table, torque\_loss (dp,w)** parameter data.



**Case 4: Efficiency Physical Signal Inputs**

If the active block variant is Input efficiencies, the leakage flow rate and friction torque calculations are as described for efficiency tabulated data (case 2). The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports EV and EM.



### Case 5: Loss Physical Signal Inputs

If the block variant is `Input losses`, the leakage flow rate and friction torque calculations are as described for loss tabulated data (case 3). The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports LV and LM.

### Characteristic Curve Visualization

If the block variant is set to `Analytical or tabulated data`, you can plot a variety of performance, efficiency, and loss curves from simulation data and component parameters. Use the context-sensitive menu of the block to plot the characteristic curves. Right-click the block to open the menu and select **Fluids > Plot characteristic**. A test harness opens with instructions on how to generate the curves.

### Assumptions

- Fluid compressibility is negligible.
- Loading on the motor shaft due to inertia, friction, and spring forces is negligible.

## Ports

### Input

#### EV — Volumetric efficiency, unitless

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

### Dependencies

This port is exposed only when the block variant is set to `Input efficiencies`.

#### EM — Mechanical efficiency, unitless

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

**Dependencies**

This port is exposed only when the block variant is set to `Input efficiencies`.

**LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the motor inlets.

**Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

**LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating motor shaft.

**Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

**Conserving****A — Motor inlet**

hydraulic (isothermal)

Hydraulic (isothermal liquid) port representing the motor inlet.

**B — Motor outlet**

hydraulic (isothermal)

Hydraulic (isothermal liquid) port representing the motor outlet.

**S — Motor shaft**

mechanical rotational

Mechanical rotational port representing the motor shaft.

**Parameters**

The exposed block parameters depend on the active block variant. See “Block Variants and Loss Parameterizations” on page 1-794.

**Modeling option — Loss parameterizations**

Analytical or tabulated data | `Input efficiencies` | `Input losses`

Set the variant for mechanical and volumetric efficiencies or losses for the block.

**Variant 1: Analytical or tabulated data****Displacement — Fluid volume displaced per unit shaft rotation angle**

30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

**Leakage and friction parameterization – Parameterization used to compute leakage flow rate and friction torque**

Analytical (default) | Tabulated data – volumetric and mechanical efficiencies |  
Tabulated data – volumetric and mechanical losses

Parameterization used to compute flow-rate and torque losses due to internal leaks and friction. The Analytical parameterization relies on nominal parameters generally available from component data sheets. The remaining, tabular, options rely on lookup tables to map pressure drop and angular velocity to component efficiencies or losses. The tabular options include:

- Tabulated data – volumetric and mechanical efficiencies
- Tabulated data – volumetric and mechanical losses

**Nominal shaft angular velocity – Shaft angular velocity at which to specify the nominal volumetric efficiency**

188 rad/s (default) | scalar with units of angle/time

Angular velocity of the rotating shaft at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using simple linear functions, the leakage flow rate and friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal pressure drop – Pressure gain at which to specify the nominal volumetric efficiency**

100e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal kinematic viscosity – Kinematic viscosity at which to specify the nominal volumetric efficiency**

18 cSt (default) | scalar with units of area/time

Kinematic viscosity of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal fluid density – Fluid density at which to specify the nominal volumetric efficiency**

900 kg/m<sup>3</sup> (default) | scalar with units of mass/volume

Mass density of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Volumetric efficiency at nominal conditions – Volumetric efficiency at the specified nominal conditions**

0.92 (default) | unitless scalar between 0 and 1

Volumetric efficiency, defined as the ratio of actual to ideal volumetric flow rates, at the specified nominal conditions. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**No-load torque – Minimum torque required to induce shaft rotation**

0.05 N\*m (default) | scalar with units of torque

Torque required to overcome seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Friction torque vs. pressure drop coefficient – Proportionality constant between friction torque and pressure drop**

0.6e-6 N\*m/Pa (default) | scalar with units of torque/pressure

Proportionality constant between the friction torque on the mechanical shaft and the pressure drop from inlet to outlet.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.



**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Pressure drop vector for efficiencies, dp – Pressure drops at which to specify the volumetric and mechanical efficiencies***M*-element vector with units of pressure (default)

*M*-element vector of pressure gains at which to specify the efficiency tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Shaft angular velocity vector for efficiencies, w – Angular velocities at which to specify the volumetric and mechanical efficiencies***N*-element vector with units of angular velocity (default)

*N*-element vector of shaft angular velocities at which to specify the efficiency tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Volumetric efficiency table, e\_v(dp,w) – Volumetric efficiencies at the specified pressure drops and angular velocities**unitless *M*-by-*N* matrix

*M*-by-*N* matrix with the volumetric efficiencies at the specified fluid pressure drops and shaft angular velocities. The efficiencies must fall in the range of 0-1. *M* and *N* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure drop vector for efficiencies, dp** parameter.

- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies**,  $w$  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  – Mechanical efficiencies at the specified pressure drops and angular velocities**

unitless  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix with the mechanical efficiencies corresponding to the specified fluid pressure drops and shaft angular velocities. The efficiencies must fall in the range of 0-1.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector for efficiencies**,  $dp$  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies**,  $w$  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motoring and pumping modes**

1e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Angular velocity threshold for pump–motor transition – Shaft angular velocity at which to initiate a smooth transition between motoring and pumping modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Check if operating beyond the quadrants of supplied tabulated data – Simulation warning mode for operating conditions outside the range of tabulated data**

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select Warning to be notified when the fluid pressure gain or shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies or Tabulated data – volumetric and mechanical losses.

#### Pressure drop vector for losses, $dp$ – Pressure drops at which to specify the volumetric and mechanical losses

*M*-element vector with units of pressure (default)

*M*-element vector of pressure drops at which to specify the loss tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Shaft angular velocity vector for losses, $w$ – Angular velocities at which to specify the volumetric and mechanical losses

*N*-element vector with units of angle/time (default)

*N*-element vector of shaft angular velocities at which to specify the component loss data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

#### Dependencies

This parameter is enabled the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Volumetric loss table, $q\_loss(dp,w)$ – Internal leakage flow rates at the specified pressure gains and angular velocities

*M*-by-*N* matrix with units of volume/time

*M*-by-*N* matrix with the volumetric gains at the specified fluid pressure drops and shaft angular velocities. Volumetric loss is defined here as the internal leakage volumetric flow rate between port A and port B. *M* and *N* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure drop vector for losses,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Mechanical loss table, $torque\_loss(dp,w)$ – Friction torques at the specified pressure gains and angular velocities

*M*-by-*N* matrix with units of torque

$M$ -by- $N$  matrix with the mechanical losses at the specified fluid pressure drops and shaft angular velocities. Mechanical loss is defined here as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector for losses,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.

### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

### Variant 2: Input efficiencies

#### **Displacement – Fluid volume displaced per unit shaft rotation angle**

30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

#### **Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal falls below the minimum volumetric efficiency, the volumetric efficiency is set to the minimum volumetric efficiency.

#### **Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal rises above the maximum volumetric efficiency, the volumetric efficiency is set to the maximum volumetric efficiency.

#### **Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal falls below the minimum mechanical efficiency, the mechanical efficiency is set to the minimum mechanical efficiency.

#### **Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at this value. If the input signal rises above the maximum mechanical efficiency, the mechanical efficiency is set to the maximum mechanical efficiency.

**Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motoring and pumping modes**

1e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for motor-pump transition – Shaft angular velocity at which to initiate a smooth transition between motoring and pumping modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Variant 3: Input losses****Displacement – Fluid volume displaced per unit shaft rotation angle**30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

**Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motoring and pumping modes**

1e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for motor-pump transition – Shaft angular velocity at which to initiate a smooth transition between motoring and pumping modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if operating beyond the motor mode — Simulation warning mode for operating conditions outside motoring mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the motoring mode. A warning is issued if the motor transitions to pumping mode. Select **Warning** to be notified when this transition occurs. The warning does not cause simulation to stop.

**Check if lower side pressure violating minimum valid condition — Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select **Warning** to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure — Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to **Warning**.

## Version History

**Introduced in R2006b**

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Fixed-Displacement Pump | Variable-Displacement Pump | Variable-Displacement Motor | Fixed-Displacement Pump (TL) | Fixed-Displacement Motor (TL)

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Fixed-Displacement Motor (IL)

Fixed-displacement motor in isothermal liquid system

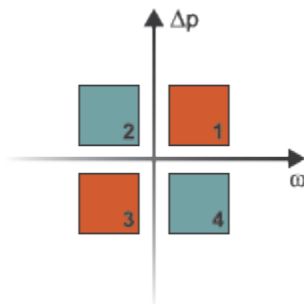
**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors



## Description

The Fixed-Displacement Motor (IL) block models a motor with constant-volume displacement. The fluid may move from port **A** to port **B**, called *forward mode*, or from port **B** to port **A**, called *reverse mode*. Motor mode operation occurs when there is a pressure drop in the direction of the flow. Pump mode operation occurs when there is a pressure gain in the direction of the flow.

Shaft rotation corresponds to the sign of the fluid volume moving through the motor. Positive fluid displacement at corresponds to positive shaft rotation in forward mode. Negative fluid displacement corresponds to negative shaft angular velocity in forward mode.



## Operation Modes

The block has eight modes of operation. The working mode depends on the pressure drop from port **A** to port **B**,  $\Delta p = p_A - p_B$  and the angular velocity,  $\omega = \omega_R - \omega_C$ :

- Mode 1, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 2, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to port **A**.
- Mode 3, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and a negative shaft angular velocity.
- Mode 4, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.

The motor block has analytical, lookup table, and physical signal parameterizations. When using tabulated data or an input signal for parameterization, you can choose to characterize the motor operation based on efficiency or losses.

In the tabulated data and the input signal parameterization options, the threshold parameters **Pressure drop threshold for motor-pump transition** and **Angular velocity threshold for motor-pump transition** identify regions where numerically smoothed flow transition between the motor operational modes can occur. Choose a transition region that provides some margin for the transition term, but which is small enough relative to the pressure and angular velocity that it will not impact calculation results.

### Analytical Leakage and Friction Parameterization

If you set **Leakage and friction parameterization** to **Analytical**, the block calculates leakage and friction from constant values of shaft velocity, pressure drop, and friction torque. The leakage flow rate, which is correlated with the pressure differential over the motor, is calculated as:

$$\dot{m}_{leak} = K\rho_{avg}\Delta p,$$

where:

- $\Delta p$  is  $p_A - p_B$ .
- $\rho_{avg}$  is the average fluid density.
- $K$  is the Hagen-Poiseuille coefficient for analytical loss,

$$K = \frac{D\omega_{nom}\left(\frac{1}{\eta_{v,nom}} - 1\right)}{\Delta p_{nom}},$$

where:

- $D$  is the **Displacement**.
- $\omega_{nom}$  is the **Nominal shaft angular velocity**.
- $\eta_{v,nom}$  is the **Volumetric efficiency at nominal conditions**.
- $\Delta p_{nom}$  is the **Nominal pressure drop**.

The friction torque, which is correlated with shaft angular velocity, is calculated as:

$$\tau_{fr} = (\tau_0 + k|\Delta p|)\tanh\left(\frac{4\omega}{5 \times 10^{-5}\omega_{nom}}\right),$$

where:

- $\tau_0$  is the **No-load torque**.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_m$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fric}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = (1 - \eta_{m,nom})D\Delta p_{nom}.$$



- $\Delta p$  is the pressure drop between ports **A** and **B**.
- $\omega$  is the relative shaft angular velocity, or  $\omega_R - \omega_C$ .

### Tabulated Data Parameterizations

When using tabulated data for motor efficiencies or losses, you can provide data for one or more of the motor operational modes. The signs of the tabulated data determine the operational regime of the block. When data is provided for less than four operational modes, the block calculates the complementing data for the other mode(s) by extending the given data into the remaining quadrants.

#### The Tabulated data - volumetric and mechanical efficiencies parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \dot{m}_{leak, motor} \left( \frac{1 + \alpha}{2} \right) + \dot{m}_{leak, pump} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\dot{m}_{leak, pump} = (\eta_v - 1) \dot{m}_{ideal}$
- $\dot{m}_{leak, motor} = (1 - \eta_v) \dot{m}$

and  $\eta_v$  is the volumetric efficiency, which is interpolated from the user-provided tabulated data. The transition term,  $\alpha$ , is

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{threshold}}\right) \tanh\left(\frac{4\omega}{\omega_{threshold}}\right),$$

where:

- $\Delta p$  is  $p_A - p_B$ .
- $p_{threshold}$  is the **Pressure drop threshold for motor-pump transition**.
- $\omega$  is  $\omega_R - \omega_C$ .
- $\omega_{threshold}$  is the **Angular velocity threshold for motor-pump transition**.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{fr, pump} \left( \frac{1 + \alpha}{2} \right) + \tau_{fr, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\tau_{fr, pump} = (\eta_m - 1) \tau$
- $\tau_{fr, motor} = (1 - \eta_m) \tau_{ideal}$

and  $\eta_m$  is the mechanical efficiency, which is interpolated from the user-provided tabulated data.

#### The Tabulated data - volumetric and mechanical losses parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{loss}(\Delta p, \omega),$$

where  $q_{loss}$  is interpolated from the **Volumetric loss table,  $q_{loss}(dp, w)$**  parameter, which is based on user-supplied data for pressure drop, shaft angular velocity, and fluid volumetric displacement.

The shaft friction torque is calculated as:

$$\tau_{fr} = \tau_{loss}(\Delta p, \omega),$$

where  $\tau_{loss}$  is interpolated from the **Mechanical loss table, torque\_loss(dp,w)** parameter, which is based on user-supplied data for pressure drop and shaft angular velocity.

### Input Signal Parameterization

When **Leakage and friction parameterization** is set to **Input signal - volumetric and mechanical efficiencies**, ports **EV** and **EM** are enabled. The internal leakage and shaft friction are calculated in the same way as the **Tabulated data - volumetric and mechanical efficiencies** parameterization, except that  $\eta_v$  and  $\eta_m$  are received directly at ports **EV** and **EM**, respectively.

When **Leakage and friction parameterization** is set to **Input signal - volumetric and mechanical losses**, ports **LV** and **LM** are enabled. These ports receive leakage flow and friction torque as positive physical signals. The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{LV} \tanh\left(\frac{4\Delta p}{p_{thresh}}\right),$$

where:

- $q_{LV}$  is the leakage flow received at port **LV**.
- $p_{thresh}$  is the **Pressure drop threshold for motor-pump transition** parameter.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{LM} \tanh\left(\frac{4\omega}{\omega_{thresh}}\right),$$

where

- $\tau_{LM}$  is the friction torque received at port **LM**.
- $\omega_{thresh}$  is the **Angular velocity threshold for motor-pump transition** parameter.

The volumetric and mechanical efficiencies range between the user-defined specified minimum and maximum values. Any values lower or higher than this range will take on the minimum and maximum specified values, respectively.

### Pump Operation

The motor flow rate is:

$$\dot{m} = \dot{m}_{ideal} + \dot{m}_{leak},$$

where  $\dot{m}_{ideal} = \rho_{avg} D \cdot \omega$ .

The motor torque is:

$$\tau = \tau_{ideal} - \tau_{fr},$$

where  $\tau_{ideal} = D \cdot \Delta p$ .

The mechanical power extracted by the motor shaft is:

$$\varphi_{mech} = \tau\omega,$$

and the motor hydraulic power is:

$$\varphi_{hyd} = \frac{\Delta p \dot{m}}{\rho_{avg}}.$$

If you would like to know if the block is operating beyond the supplied tabulated data, you can set **Check if operating beyond the quadrants of supplied tabulated data** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs. For parameterization by input signal for volumetric or mechanical losses, you can be notified if the simulation surpasses operating modes with the **Check if operating outside of motor mode** parameter.

You can also monitor motor functionality. Set **Check if pressures are less than motor minimum pressure** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs.

### Predefined Parameterization

Pre-parameterized manufacturer data is available for this block. This data allows you to model a specific supplier component.

To load a predefined parameterization,

- 1 Click the "Select a predefined parameterization" hyperlink in the block dialog description.
- 2 Select a part from the drop-down menu and click **Update block with selected part**.
- 3 If you change any parameter settings after loading a parameterization, you can check your changes by clicking **Compare block settings with selected part**. Any difference in settings between the block and pre-defined parameterization will display in the MATLAB command window.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see "List of Pre-Parameterized Components".

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Entry or exit port to the motor.

#### B — Liquid port

isothermal liquid

Entry or exit port to the motor.

**R – Mechanical port**

mechanical rotational

Rotating shaft angular velocity and torque.

**C – Mechanical port**

mechanical rotational

Motor casing reference angular velocity and torque.

**Input****EV – Volumetric efficiency**

physical signal

Motor efficiency for fluid displacement, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**EM – Mechanical efficiency**

physical signal

Motor efficiency for the mechanical extraction of energy, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**LV – Leakage flow rate, m<sup>3</sup>/s**

physical signal

Motor losses associated with fluid displacement in m<sup>3</sup>/s, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**LM – Friction torque, N\*m**

physical signal

Motor losses associated with the mechanical extraction of energy in N\*m, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Parameters

### Leakage and friction parameterization — Method of calculating leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Parameterization of the leakage and friction characteristics of the pump.

- In the **Analytical** parameterization, the leakage flow rate and the friction torque are calculated by analytical equations.
- In the **Tabulated data - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are calculated from the user-supplied **Pressure drop vector,  $\mathbf{dp}$**  and **Shaft angular velocity vector,  $\mathbf{w}$**  parameters and interpolated from the 2-D dependent **Volumetric efficiency table,  $e_v(\mathbf{dp},\mathbf{w})$**  and **Mechanical efficiency table,  $e_m(\mathbf{dp},\mathbf{w})$**  tables.
- In the **Tabulated data - volumetric and mechanical loss** parameterization, the leakage flow rate and torque friction are calculated from user-supplied **Pressure drop vector,  $\mathbf{dp}$**  and **Shaft angular velocity vector,  $\mathbf{w}$**  parameters and interpolated from the 2-D dependent **Volumetric loss table,  $q_{loss}(\mathbf{dp},\mathbf{w})$**  and **Mechanical loss table,  $torque_{loss}(\mathbf{dp},\mathbf{w})$**  tables.
- In the **Input signal - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are received as physical signals at ports **EV** and **EM**, respectively.
- In the **Input signal - volumetric and mechanical loss** parameterization, the leakage flow rate and torque friction are received as physical signals at ports **LV** and **LM**, respectively.

### Displacement — Fixed-volume fluid displacement

30 cm<sup>3</sup>/rev (default) | scalar

Amount of fixed-volume fluid displacement.

### Nominal shaft angular velocity — Shaft angular velocity

188 rad/s (default) | scalar

Angular velocity of the shaft under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Nominal pressure drop — Pressure drop between fluid entry and exit

10 MPa (default) | scalar

Motor pressure drop between the fluid entry and exit under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Volumetric efficiency at nominal conditions — Ratio of actual flow rate to ideal flow rate at nominal conditions

0.92 (default) | positive scalar in the range of (0,1]

Ratio of actual flow rate to ideal flow rate at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Baseline torque**

0 N\*m (default) | scalar

Minimum value of torque to overcome seal friction and induce shaft motion.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of actual torque to ideal torque generated**

0.88 (default) | positive scalar

Ratio of actual torque to ideal torque generated at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Pressure drop vector, dp – Vector of pressure data for tabulated data parameterization**

[.1, 1, 2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** parameter for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w)** and **Mechanical efficiency table, e\_m(dp,w)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Shaft angular velocity vector, w – Vector of angular velocity data for tabulated data parameterization**

[25, 50, 100, 200, 300, 400] rad/s (default) | 1-by-n vector

Vector of angular velocity data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** parameter for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w)** and **Mechanical efficiency table, e\_m(dp,w)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Volumetric efficiency table,  $e_v(dp,w)$  — Volumetric efficiency for tabulated data parameterization**

[.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric efficiencies at the specified fluid pressure drop and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  — Mechanical efficiency for tabulated data parameterization**

[.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984] (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mechanical efficiencies at the specified fluid pressure drop and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric loss table,  $q_{loss}(dp,w)$  — Volumetric losses for tabulated data parameterization**

[.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] \*  $1e-3$  m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric efficiencies at the specified fluid pressure drop and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Mechanical loss table,  $torque_{loss}(dp,w)$  — Mechanical losses for tabulated data parameterization**

[.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505; .1937, .1937, .1833, .1833, .1729, .1626] N\*m (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of mechanical losses at the specified fluid pressure drop and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

#### **Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

#### **Minimum volumetric efficiency – Minimum value of volumetric efficiency**

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of volumetric efficiency. If the input signal is below this value, the volumetric efficiency is set to the minimum volumetric efficiency.

#### **Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **Maximum volumetric efficiency – Maximum value of volumetric efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of volumetric efficiency. If the input signal is above this value, the volumetric efficiency is set to the maximum volumetric efficiency.

#### **Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **Minimum mechanical efficiency – Minimum value of mechanical efficiency**

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of mechanical efficiency. If the input signal is below this value, the mechanical efficiency is set to the minimum mechanical efficiency.

#### **Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **Maximum mechanical efficiency – Maximum value of mechanical efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of mechanical efficiency. If the input signal is above this value, the mechanical efficiency is set to the maximum mechanical efficiency.

#### **Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.



**Pressure drop threshold for motor-pump transition – Pressure threshold for mode transition**

1e-3 MPa (default) | positive scalar

Threshold pressure drop value for the transition between pump and motor functionality. A transition region is defined around 0 MPa between the positive and negative values of the pressure drop threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Angular velocity threshold for motor-pump transition – Angular velocity threshold for mode transition**

10 rad/s (default) | positive scalar

Threshold angular velocity value for the transition between pump and motor functionality. A transition region is defined around 0 rad/s between the positive and negative values of the angular velocity threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Check if operating beyond the quadrants of supplied tabulated data – Whether to notify if extents of supplied data are surpassed**

None (default) | Warning | Error

Whether to notify if the extents of the supplied data are surpassed. Select Warning to be notified when the block uses values beyond the supplied data range. Select Error to stop the simulation when the block uses values beyond the supplied data range.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating outside of motor mode – Whether to notify if block operates outside of the motor mode functionality**

None (default) | Warning | Error

Whether to notify if block operates outside of the motor mode functionality. This block has four operation modes: forward motor, reverse motor, reverse pump, and forward pump. Select **Warning** to be notified when the block operates in the forward or reverse motor pump modes. Select **Error** to stop the simulation when the block operates in the forward or reverse pump modes.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical losses`.

**Check if pressures are less than motor minimum pressure — Whether to notify if fluid exit pressure is low**

None (default) | Warning | Error

Whether to notify if the fluid at port **A** or **B** experiences low pressure. Select **Warning** to be notified when the outlet pressure falls below a minimum specified value. Select **Error** to stop the simulation when the outlet pressure falls below a minimum specified value.

The parameter helps identify potential conditions for cavitation, when the fluid pressure falls below the fluid vapor pressure.

**Motor minimum pressure — Lower threshold to acceptable pressure at the motor outlet**

0.101325 MPa (default) | positive scalar

Lower threshold of acceptable pressure at the motor inlet or outlet.

**Dependencies**

To enable this parameter, set **Check if pressures are less than motor minimum pressure** to either:

- Warning
- Error

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Variable-Displacement Motor (IL) | Fixed-Displacement Motor (TL) | Fixed-Displacement Pump (IL)

## Fixed-Displacement Motor (TL)

Hydraulic-mechanical power conversion device

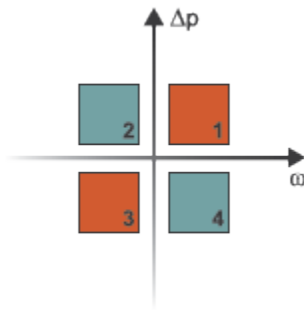
**Library:** Simscape / Fluids / Thermal Liquid / Pumps & Motors



### Description

The Fixed-Displacement Motor (TL) block represents a device that extracts power from a thermal liquid network and delivers it to a mechanical rotational network. The motor displacement is fixed at a constant value that you specify through the **Displacement** parameter.

Ports **A** and **B** represent the motor inlets. Ports **R** and **C** represent the motor drive shaft and case. During normal operation, a pressure drop from port **A** to port **B** causes a positive flow rate from port **A** to port **B** and a positive rotation of the motor shaft relative to the motor case. This operation mode is referred to here as *forward motor*.



### Operation Modes

The block has four modes of operation. The working mode depends on the pressure drop from port **A** to port **B**,  $\Delta p = p_B - p_A$  and the angular velocity,  $\omega = \omega_R - \omega_C$ :

- Mode 1, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 2, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to port **A**.
- Mode 3, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and a negative shaft angular velocity.
- Mode 4, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.

The response time of the motor is considered negligible in comparison with the system response time. The motor is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.

### Energy Balance

Mechanical work done by the pump is associated with an energy exchange. The governing energy balance equation is:

$$\phi_A + \phi_B - P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is the motor hydraulic power. It is a function of the pressure difference between the motor ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$

The motor mechanical power is generated from the motor torque,  $\tau$  and angular velocity,  $\omega$ :

$$P_{mech} = T\omega.$$

### Flow Rate and Driving Torque

The mass flow rate generated at the motor is

$$\dot{m} = \dot{m}_{Ideal} + \dot{m}_{Leak},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{Ideal}$  is the ideal mass flow rate.
- $\dot{m}_{Leak}$  is the internal leakage mass flow rate.

The torque generated at the motor is

$$\tau = \tau_{Ideal} - \tau_{Friction},$$

where:

- $\tau$  is the actual torque.
- $\tau_{Ideal}$  is the ideal torque.
- $\tau_{Friction}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal mass flow rate is

$$\dot{m}_{Ideal} = \rho D\omega,$$

and the ideal generated torque is

$$\tau_{Ideal} = D\Delta p,$$

where:

- $\rho$  is the average of the fluid densities at thermal liquid ports **A** and **B**.
- $D$  is the **Displacement** parameter.

- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure drop from inlet to outlet.

### Leakage and friction parameterization

You can parameterize leakage and friction analytically, using tabulated efficiencies or losses, or by input efficiencies or input losses.

#### Analytical

When you set **Leakage and Friction Parameterization** to **Analytical**, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}}\rho_{\text{Avg}}\Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}}|\Delta p|\tanh\left(\frac{4\omega}{(5 \cdot 10^{-5})\omega_{\text{Nom}}}\right) \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the thermal liquid, taken here as the average of its values at the thermal liquid ports.
- $K_{\text{TP}}$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_m$ :

$$k = \frac{\tau_{fr, \text{nom}} - \tau_0}{\Delta p_{\text{nom}}}.$$

$\tau_{fr}$  is the friction torque at nominal conditions:

$$\tau_{fr, \text{nom}} = (1 - \eta_{m, \text{nom}})D\Delta p_{\text{nom}}.$$

- $\tau_0$  is the specified value of the **No-load torque** parameter.
- $\omega_{\text{Nom}}$  is the specified value of the **Nominal shaft angular velocity** parameter.
- $\Delta p_{\text{Nom}}$  is the specified value of the **Nominal pressure drop** parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.

The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{\text{HP}} = \frac{D\omega_{\text{Nom}}\mu_{\text{Nom}}\left(\frac{1}{\eta_{v, \text{Nom}}} - 1\right)}{\Delta p_{\text{Nom}}},$$

where:

- $\omega_{\text{Nom}}$  is the specified value of the **Nominal shaft angular velocity** parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.

- $\mu_{\text{Nom}}$  is the specified value of the **Nominal Dynamic viscosity** block parameter. This is the dynamic viscosity at which the nominal volumetric efficiency is specified.
- $\eta_{\text{v,Nom}}$  is the specified value of the **Volumetric efficiency at nominal conditions** block parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.

### Tabulated Efficiencies

When you set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \dot{m}_{\text{Leak,Motor}} \frac{(1 + \alpha)}{2} + \dot{m}_{\text{Leak,Pump}} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{\text{Friction}} = \tau_{\text{Friction,Motor}} \frac{1 + \alpha}{2} + \tau_{\text{Friction,Pump}} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\dot{m}_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4D}{D_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure drop threshold for motor-pump transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.
- $D_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.

The leakage flow rate is calculated from the volumetric efficiency, a quantity that is specified in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain via the **Volumetric efficiency table** block parameter. When operating in motor mode (quadrants **1** and **3** of the  $\Delta p$ - $\omega$ - $D$  chart shown in the "Operation Modes" on page 1-793 figure), the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = (1 - \eta_{\text{v}})\dot{m},$$

where  $\eta_{\text{v}}$  is the volumetric efficiency, obtained either by interpolation or extrapolation of the tabulated data. Similarly, when operating in pump mode (quadrants **2** and **4** of the  $\Delta p$ - $\omega$ - $D$  chart), the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = -(1 - \eta_{\text{v}})\dot{m}_{\text{Ideal}}.$$

The friction torque is similarly calculated from the mechanical efficiency, a quantity that is specified in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain via the **Mechanical efficiency table** block parameter. When operating in motor mode (quadrants **1** and **3** of the  $\Delta p$ - $\omega$ - $D$  chart):

$$\tau_{\text{Friction, Motor}} = (1 - \eta_m)\tau_{\text{Ideal}},$$

where  $\eta_m$  is the mechanical efficiency, obtained either by interpolation or extrapolation of the tabulated data. Similarly, when operating in pump mode (quadrants **2** and **4** of the  $\Delta p$ - $\omega$ - $D$  chart):

$$\tau_{\text{Friction, Pump}} = -(1 - \eta_m)\tau.$$

### Tabulated Losses

When you set **Leakage and friction parameterization** to **Tabulated data - volumetric and mechanical losses**, the leakage (volumetric) flow rate is specified directly in tabulated form over the  $\Delta p$ - $\omega$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega).$$

The mass flow rate due to leakage is calculated from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The friction torque is similarly specified in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega),$$

where  $q_{\text{Leak}}(\Delta p, \omega)$  and  $\tau_{\text{Friction}}(\Delta p, \omega)$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the tabulated data specified via the **Volumetric loss table** and **Mechanical loss table** block parameters.

### Input Efficiencies

When you set **Leakage and friction parameterization** to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports **EV** and **EM**.

The efficiencies are positive quantities with value between 0 and 1. Input values outside of these bounds are set equal to the nearest bound (0 for inputs smaller than 0, 1 for inputs greater than 1). The efficiency signals are saturated at the **Minimum volumetric efficiency** or **Minimum mechanical efficiency** and **Maximum volumetric efficiency** or **Maximum mechanical efficiency**.

### Input Losses

When you set **Leakage and friction parameterization** to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports **LV** and **LM**.

The block expects the inputs to be positive. It sets the signs automatically from the operating conditions established during simulation—more precisely, from the  $\Delta p$ - $\omega$  quadrant in which the component happens to be operating.

### **Assumptions and Limitations**

- The motor is treated as a quasi-steady component.
- The effects of fluid inertia and elevation are ignored.
- The motor wall is rigid.
- External leakage is ignored.

### **Ports**

#### **Input**

##### **EV — Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

##### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

##### **EM — Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

##### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

##### **LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the motor inlets.

##### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

##### **LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating motor shaft.

##### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.



## Conserving

### A – Motor inlet

thermal liquid

Thermal liquid conserving port associated with the motor inlet.

### B – Motor outlet

thermal liquid

Thermal liquid conserving port associated with the motor outlet.

### C – Motor Case

mechanical rotational

Mechanical rotational conserving port associated with the motor case.

### R – Motor Shaft

mechanical rotational

Mechanical rotational conserving port associated with the rotational motor shaft.

## Parameters

### Leakage and friction parameterization – Parameterization of leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute flow-rate and torque losses due to internal leaks and friction. When you select Analytical, the block parameters are generally available from component data sheets. When you select Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses, the block uses lookup tables to map pressure drop, angular velocity, and displacement to component efficiencies or losses.

When you select Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses, the block performs the leakage flow rate and friction torque calculations the same as the Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses settings, respectively. When you select Input signal - volumetric and mechanical efficiencies the block enables the physical signal ports, **EV** and **EM**. You use these ports to specify the volumetric and mechanical efficiency. When you select Input signal - volumetric and mechanical losses the block enables the physical signal ports, **LV** and **LM**. You use these ports to specify the volumetric and mechanical losses.

### Displacement – Fluid volume displaced per shaft rotation

30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid volume displaced per shaft rotation. The block maintains this value throughout the simulation.

### Nominal shaft angular velocity – Shaft angular velocity for given volumetric efficiency

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. These values are typically available at standard operating conditions in the manufacturer data sheet. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal pressure drop – Pressure drop for corresponding volumetric efficiency**

10 MPa (default) | scalar

Pressure drop that corresponds to the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal dynamic viscosity – Dynamic viscosity at which to specify the volumetric efficiency**

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Volumetric efficiency at nominal conditions – Volumetric efficiency at the specified nominal conditions**

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of actual to ideal mechanical power**

0.88 (default) | positive scalar

Ratio of actual mechanical power to ideal mechanical power at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Minimum torque required to induce shaft rotation**

0 N\*m (default) | scalar

Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Pressure drop vector, **dp** — Pressure drops for given volumetric and mechanical efficiencies

[.1, 1, 2] MPa (default) | vector

Pressure drops for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single quadrant, ( $\omega$ ,  $\Delta p$ ). Refer to the block description for the operation modes corresponding to the various quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Shaft angular velocity vector, **w** — Angular velocities at which to specify the volumetric and mechanical efficiencies

[25, 50, 100, 200, 300, 400] rad/s | vector

Shaft angular velocities for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single quadrant, ( $\omega$ ,  $\Delta p$ ). Refer to the block description for the operation modes corresponding to the various quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Volumetric efficiency table, **e\_v(dp,w)** — Volumetric efficiencies for given pressure drops and angular velocities

[.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91] | matrix

Volumetric efficiencies for the given fluid pressure drops and shaft angular velocities.. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector, dp** parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector, w** parameter.

You can specify the data for a single quadrant, ( $\omega$ ,  $\Delta p$ ). Refer to the block description for the operation modes corresponding to the various quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  — Mechanical efficiencies for given pressure drops and angular velocities**

[.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984] | matrix

Mechanical efficiencies for the given fluid pressure drops and shaft angular velocities. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

You can specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to the block description for the operation modes corresponding to the various quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Pressure drop vector,  $dp$  — Pressure drop for corresponding losses**

[.1, 1, 2] MPa (default)

Pressure drops for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to the block description for the operation modes corresponding to the various quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Shaft angular velocity vector,  $w$  — Shaft speed for corresponding losses**

[25, 50, 100, 200, 300, 400] rad/s (default)

Shaft angular velocity for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to the block description for the operation modes corresponding to the various quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Volumetric loss table,  $q_{loss}(dp,w)$  — Internal leakage flow rates for corresponding pressure drops and angular velocities**

[.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] \*  $1e-3$  m<sup>3</sup>/s

Volumetric losses at the specified fluid pressure drops and shaft angular velocities. Volumetric loss is defined here as the internal leakage volumetric flow rate between port A and port B.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

You can specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to the block description for the operation modes corresponding to the various quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

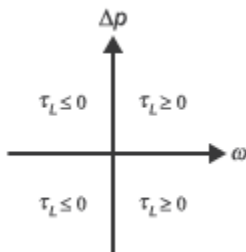
#### Mechanical loss table, torque\_loss(dp,w) – Friction torques for the corresponding pressure drops and angular velocities

[.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505  
; .1937, .1937, .1833, .1833, .1729, .1626] N\*m

Mechanical losses for the given pressure drops and shaft angular velocities. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

You can specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to the block description for the operation modes corresponding to the various quadrants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

#### Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | scalar in the range (0,1)

Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motor and pump modes**

1e-3 MPa (default) | scalar

Pressure drop from inlet to outlet below which the block begins to transition between motoring and pumping modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Angular velocity threshold for motor-pump transition – Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between motoring and pumping modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Cross-sectional area at ports A and B — Flow area at the component inlet and outlet**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

**Check if operating beyond the quadrants of supplied tabulated data — Simulation warning mode for operating conditions outside the range of tabulated data**

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select **Warning** to be notified when the fluid pressure drop or shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Check if operating outside of motor mode — Simulation warning mode for operating conditions outside motoring mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the motoring mode. The block generates a warning if the motor transitions to pumping mode. Select **Warning** to be notified when this transition occurs. The warning does not cause simulation to stop.

**Version History**

Introduced in R2016a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

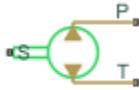
**See Also**

Fixed-Displacement Pump (TL)

# Fixed-Displacement Pump

Mechanical-to-hydraulic power conversion device

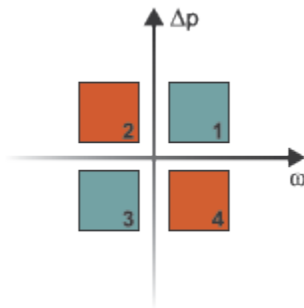
**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Fixed-Displacement Pump block represents a device that extracts power from a mechanical rotational network and delivers it to a hydraulic (isothermal liquid) network. The pump displacement is fixed at a constant value that you specify through the **Displacement** parameter.

Ports **T** and **P** represent the pump inlets. Port **S** represents the pump drive shaft. During normal operation, the pressure gain from port **T** to port **P** is positive if the angular velocity at port **S** is positive also. This operation mode is referred to here as *forward pump*.



## Operation Modes

A total of four operation modes are possible. The working mode depends on the pressure gain from port **T** to port **P** ( $\Delta p$ ) and on the angular velocity at port **S** ( $\omega$ ). The “Operation Modes” on page 1-834 figure maps the modes to the quadrants of a  $\Delta p$ - $\omega$  chart. The modes are labeled 1-4:

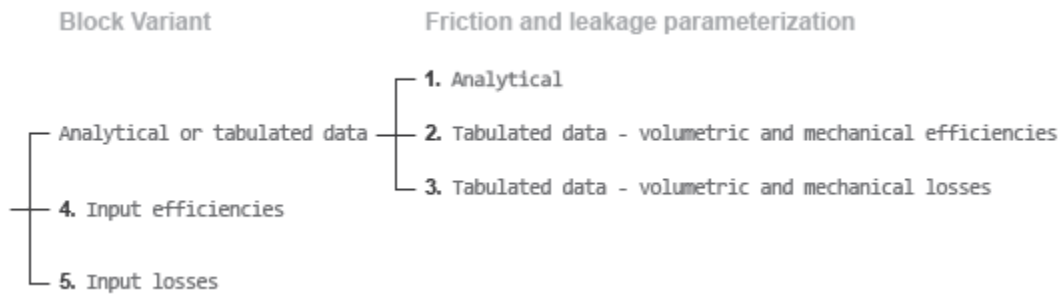
- Mode **1**: forward pump — A positive shaft angular velocity generates a positive pressure gain.
- Mode **2**: reverse motor — A negative pressure drop (shown in the figure as a positive pressure gain) generates a negative shaft angular velocity.
- Mode **3**: reverse pump — A negative shaft angular velocity generates a negative pressure gain.
- Mode **4**: forward motor — A positive pressure drop (shown in the figure as a negative pressure gain) generates a positive shaft angular velocity.

The response time of the pump is considered negligible in comparison with the system response time. The pump is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.



## Block Variants and Loss Parameterizations

The pump model accounts for power losses due to leakage and friction. Leakage is internal and occurs between the pump inlet and outlet only. The block computes the leakage flow rate and friction torque using your choice of five loss parameterizations. You select a parameterization using block variants and, in the Analytical or tabulated data case, the **Leakage and friction parameterization** parameter.



## Loss Parameterizations

The block provides three Simscape variants to select from. To change the active block variant, use the **Modeling option** parameter. The available variants are:

- **Analytical or tabulated data** — Obtain the mechanical and volumetric efficiencies or losses from analytical models based on nominal parameters or from tabulated data. Use the **Leakage and friction parameterization** parameter to select the exact input type.
- **Input efficiencies** — Provide the mechanical and volumetric efficiencies directly through physical signal input ports.
- **Input losses** — Provide the mechanical and volumetric losses directly through physical signal input ports. The mechanical loss is defined as the internal friction torque. The volumetric loss is defined as the internal leakage flow rate.

## Flow Rate and Driving Torque

The volumetric flow rate generated at the pump is

$$q = q_{\text{Ideal}} + q_{\text{Leak}}$$

where:

- $q$  is the net volumetric flow rate.
- $q_{\text{Ideal}}$  is the ideal volumetric flow rate.
- $q_{\text{Leak}}$  is the internal leakage volumetric flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{\text{Ideal}} + \tau_{\text{Friction}}$$

where:

- $\tau$  is the net driving torque.

- $\tau_{\text{Ideal}}$  is the ideal driving torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal volumetric flow rate is

$$q_{\text{Ideal}} = D\omega,$$

and the ideal driving torque is

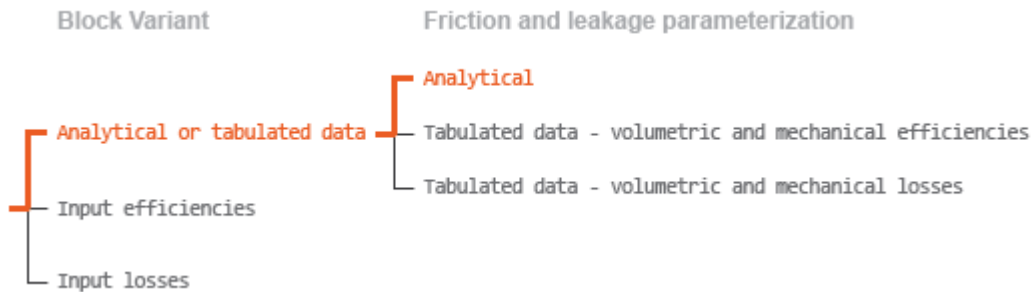
$$\tau_{\text{Ideal}} = D\Delta p,$$

where:

- $D$  is the specified value of the **Displacement** block parameter.
- $\omega$  is the instantaneous angular velocity of the rotary shaft.
- $\Delta p$  is the instantaneous pressure gain from inlet to outlet.

### Leakage Flow Rate and Friction Torque

The internal leakage flow rate and friction torque calculations depend on the block variant selected. If the block variant is **Analytical** or **tabulated data**, the calculations depend also on the **Leakage and friction parameterization** parameter setting. There are five possible permutations of block variant and parameterization settings.



### Case 1: Analytical Efficiency Calculation

If the active block variant is **Analytical** or **tabulated data** and the **Leakage and friction parameterization** parameter is set to **Analytical**, the leakage flow rate is

$$q_{\text{Leak}} = K_{\text{HP}}\Delta p,$$

and the friction torque is

$$\tau_{\text{Friction}} = (\tau_0 + K_{\text{TP}}|\Delta p|)\tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.

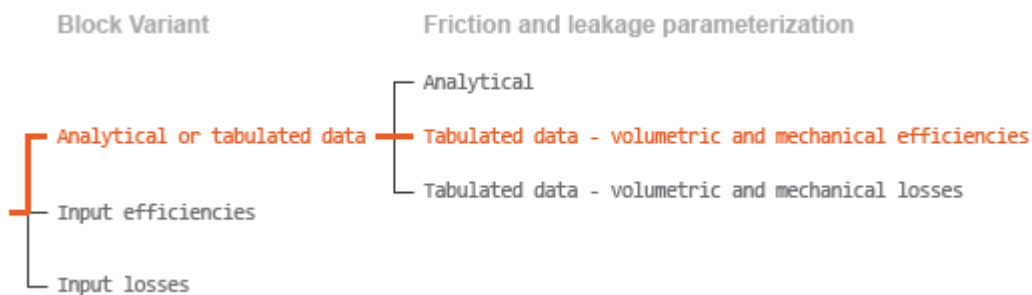
- $K_{TP}$  is the specified value of the **Friction torque vs pressure gain coefficient** block parameter.
- $\tau_0$  is the specified value of the **No-load torque** block parameter.
- $\omega_{Threshold}$  is the threshold angular velocity for the motor-pump transition. The threshold angular velocity is an internally set fraction of the specified value of the **Nominal shaft angular velocity** block parameter.

The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{HP} = \frac{\nu_{Nom} \rho_{Nom} \omega_{Nom} D_{Max}}{\rho v \Delta p_{Nom}} (1 - \eta_{v,Nom}),$$

where:

- $\nu_{Nom}$  is the specified value of the **Nominal kinematic viscosity** block parameter. This is the kinematic viscosity at which the nominal volumetric efficiency is specified.
- $\rho_{Nom}$  is the specified value of the **Nominal fluid density** block parameter. This is the density at which the nominal volumetric efficiency is specified.
- $\omega_{Nom}$  is the specified value of the **Nominal shaft angular velocity** block parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.
- $\rho$  is the actual fluid density in the attached hydraulic (isothermal liquid) network. This density can differ from the specified value of the **Nominal fluid density** block parameter.
- $v$  is the kinematic viscosity of the fluid associated with the fluid network.
- $\Delta p_{Nom}$  is the specified value of the **Nominal pressure gain** block parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.
- $\eta_{v,Nom}$  is the specified value of the **Volumetric efficiency at nominal conditions** block parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.



## Case 2: Efficiency Tabulated Data

If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies, the leakage flow rate is

$$q_{Leak} = q_{Leak,Pump} \frac{(1 + \alpha)}{2} + q_{Leak,Motor} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{Friction} = \tau_{Friction,Pump} \frac{1 + \alpha}{2} + \tau_{Friction,Motor} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the pump-pump transition.
- $q_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $q_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure drop threshold for motor-pump transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.

The leakage flow rate is computed from efficiency tabulated data through the equation

$$q_{\text{Leak,Pump}} = (1 - \eta_v)q_{\text{Ideal}},$$

in pump mode and through the equation

$$q_{\text{Leak,Motor}} = -(1 - \eta_v)q,$$

in motor mode, where:

- $\eta_v$  is the volumetric efficiency obtained through interpolation or extrapolation of the **Volumetric efficiency table, e\_v(dp,w)** parameter data.

Similarly, the friction torque is computed from efficiency tabulated data through the equation

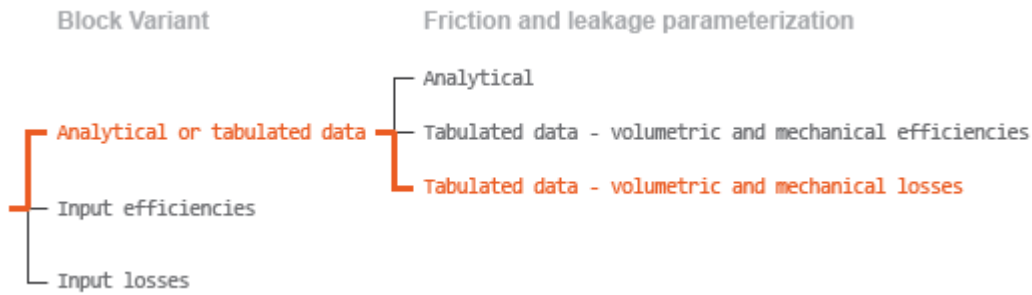
$$\tau_{\text{Friction,Pump}} = (1 - \eta_m)\tau,$$

in pump mode and through the equation

$$\tau_{\text{Friction,Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}},$$

in motor mode, where:

- $\eta_m$  is the mechanical efficiency obtained through interpolation or extrapolation of the **Mechanical efficiency table, e\_m(dp,w)** parameter data.



### Case 3: Loss Tabulated Data

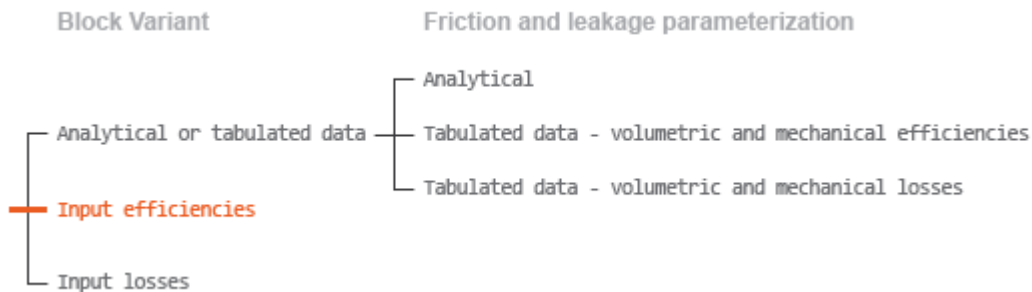
If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses, the leakage flow rate equation is

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega).$$

and the friction torque equation is

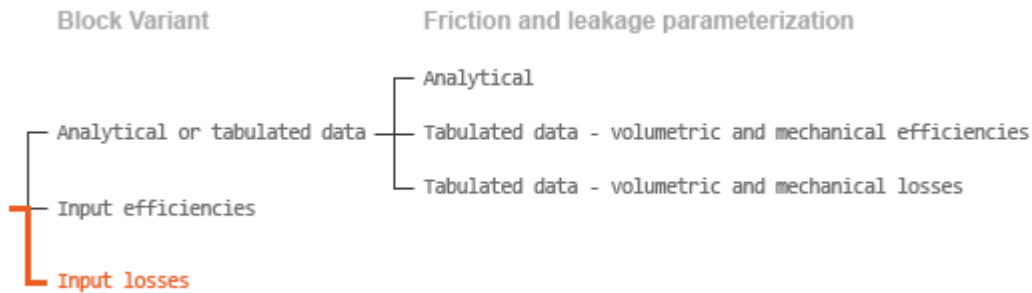
$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega),$$

where  $q_{\text{Leak}}(\Delta p, \omega)$  and  $\tau_{\text{Friction}}(\Delta p, \omega)$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the **Volumetric loss table,  $q_{\text{loss}}(\Delta p, \omega)$**  and **Mechanical loss table, torque\_loss ( $\Delta p, \omega$ )** parameter data.



### Case 4: Efficiency Physical Signal Inputs

If the active block variant is Input efficiencies, the leakage flow rate and friction torque calculations are as described for efficiency tabulated data (case 2). The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports EV and EM.



### Case 5: Loss Physical Signal Inputs

If the block variant is `Input losses`, the leakage flow rate and friction torque calculations are as described for loss tabulated data (case 3). The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports LV and LM.

### Characteristic Curve Visualization

If the block variant is set to `Analytical or tabulated data`, you can plot a variety of performance, efficiency, and loss curves from simulation data and component parameters. Use the context-sensitive menu of the block to plot the characteristic curves. Right-click the block to open the menu and select **Fluids > Plot characteristic**. A test harness opens with instructions on how to generate the curves.

### Assumptions

- Fluid compressibility is negligible.
- Loading on the pump shaft due to inertia, friction, and spring forces is negligible.

## Ports

### Input

#### EV — Volumetric efficiency, unitless

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

### Dependencies

This port is exposed only when the block variant is set to `Input efficiencies`.

#### EM — Mechanical efficiency, unitless

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

**Dependencies**

This port is exposed only when the block variant is set to `Input efficiencies`.

**LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the pump inlets.

**Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

**LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating pump shaft.

**Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

**Conserving****P — Pump outlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the pump outlet.

**T — Pump inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the pump inlet.

**S — Pump shaft**

mechanical rotational

Mechanical rotational conserving port representing the pump shaft.

**Parameters**

The exposed block parameters depend on the active block variant. See “Block Variants and Loss Parameterizations” on page 1-835.

**Modeling option — Loss parameterizations**

Analytical or tabulated data | `Input efficiencies` | `Input losses`

Set the variant for mechanical and volumetric efficiencies or losses for the block.

**Variant 1: Analytical or tabulated data****Displacement — Fluid volume displaced per unit shaft rotation angle**

30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

**Leakage and friction parameterization – Parameterization used to compute leakage flow rate and friction torque**

Analytical (default) | Tabulated data – volumetric and mechanical efficiencies | Tabulated data – volumetric and mechanical losses

Parameterization used to compute flow-rate and torque losses due to internal leaks and friction. The Analytical parameterization relies on nominal parameters generally available from component data sheets. The remaining, tabular, options rely on lookup tables to map pressure drop and angular velocity to component efficiencies or losses. The tabular options include:

- Tabulated data – volumetric and mechanical efficiencies
- Tabulated data – volumetric and mechanical losses

**Nominal shaft angular velocity – Shaft angular velocity at which to specify the nominal volumetric efficiency**

188 rad/s (default) | scalar with units of angle/time

Angular velocity of the rotating shaft at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using simple linear functions, the leakage flow rate and friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal pressure gain – Pressure gain at which to specify the nominal volumetric efficiency**

100e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal kinematic viscosity – Kinematic viscosity at which to specify the nominal volumetric efficiency**

18 cSt (default) | scalar with units of area/time

Kinematic viscosity of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.



**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal fluid density – Fluid density at which to specify the nominal volumetric efficiency**

900 kg/m<sup>3</sup> (default) | scalar with units of mass/volume

Mass density of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Volumetric efficiency at nominal conditions – Volumetric efficiency at the specified nominal conditions**

0.92 (default) | unitless scalar between 0 and 1

Volumetric efficiency, defined as the ratio of actual to ideal volumetric flow rates, at the specified nominal conditions. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**No-load torque – Minimum torque required to induce shaft rotation**

0.05 N\*m (default) | scalar with units of torque

Torque required to overcome seal friction and induce rotation of the mechanical shaft. This torque is the smoothed load-independent component of the total friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Friction torque vs. pressure gain coefficient – Proportionality constant between friction torque and pressure gain**

0.6e-6 N\*m/Pa (default) | scalar with units of torque/pressure

Proportionality constant between the friction torque on the mechanical shaft and the pressure gain from inlet to outlet.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Pressure gain vector for efficiencies, dp – Pressure gains at which to specify the volumetric and mechanical efficiencies***M*-element vector with units of pressure (default)

*M*-element vector of pressure gains at which to specify the efficiency tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Shaft angular velocity vector for efficiencies, w – Angular velocities at which to specify the volumetric and mechanical efficiencies***N*-element vector with units of angular velocity (default)

*N*-element vector of shaft angular velocities at which to specify the efficiency tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Volumetric efficiency table, e\_v(dp,w) – Volumetric efficiencies at the specified pressure gains and angular velocities**unitless *M*-by-*N* matrix

*M*-by-*N* matrix with the volumetric efficiencies at the specified fluid pressure gains and shaft angular velocities. The efficiencies must fall in the range of 0-1. *M* and *N* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure gain vector for efficiencies, dp** parameter.

- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### **Mechanical efficiency table, $e_m(dp,w)$ – Mechanical efficiencies at the specified pressure gains and angular velocities**

unitless  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix with the mechanical efficiencies corresponding to the specified fluid pressure gains and shaft angular velocities. The efficiencies must fall in the range of 0-1.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector for efficiencies,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### **Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between pumping and motoring modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between pumping and motoring modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### **Angular velocity threshold for pump–motor transition – Shaft angular velocity at which to initiate a smooth transition between pumping and motoring modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between pumping and motoring modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### **Check if operating beyond the quadrants of supplied tabulated data – Simulation warning mode for operating conditions outside the range of tabulated data**

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select Warning to be notified when the fluid pressure gain or shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies or Tabulated data – volumetric and mechanical losses.

#### Pressure gain vector for losses, $dp$ – Pressure gains at which to specify the volumetric and mechanical losses

*M*-element vector with units of pressure (default)

*M*-element vector of pressure gains at which to specify the loss tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Shaft angular velocity vector for losses, $w$ – Angular velocities at which to specify the volumetric and mechanical losses

*N*-element vector with units of angle/time (default)

*N*-element vector of shaft angular velocities at which to specify the component loss data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Volumetric loss table, $q\_loss(dp,w)$ – Internal leakage flow rates at the specified pressure gains and angular velocities

*M*-by-*N* matrix with units of volume/time

*M*-by-*N* matrix with the volumetric gains at the specified fluid pressure gains and shaft angular velocities. Volumetric loss is defined here as the internal leakage volumetric flow rate between port A and port B. *M* and *N* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure gain vector for losses,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### Mechanical loss table, $torque\_loss(dp,w)$ – Friction torques at the specified pressure gains and angular velocities

*M*-by-*N* matrix with units of torque

$M$ -by- $N$  matrix with the mechanical losses at the specified fluid pressure gains and shaft angular velocities. Mechanical loss is defined here as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector for losses,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.

### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

### Variant 2: Input efficiencies

#### Displacement – Fluid volume displaced per unit shaft rotation angle

30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

#### Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal falls below the minimum volumetric efficiency, the volumetric efficiency is set to the minimum volumetric efficiency.

#### Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal rises above the maximum volumetric efficiency, the volumetric efficiency is set to the maximum volumetric efficiency.

#### Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal falls below the minimum mechanical efficiency, the mechanical efficiency is set to the minimum mechanical efficiency.

#### Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal rises above the maximum mechanical efficiency, the mechanical efficiency is set to the maximum mechanical efficiency.

**Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between motor and pump modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for pump–motor transition – Shaft angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Variant 3: Input losses****Displacement – Fluid volume displaced per unit shaft rotation angle**30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Fluid volume displaced per unit shaft rotation angle. The displacement is fixed at this value during simulation. The specified value must be greater than zero.

**Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between motor and pump modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for pump–motor transition – Shaft angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

### **Check if operating beyond the pump mode — Simulation warning mode for operating conditions outside pumping mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the pumping mode. A warning is issued if the pump transitions to motoring mode. Select **Warning** to be notified when this transition occurs. The warning does not cause simulation to stop.

### **Check if lower side pressure violating minimum valid condition — Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select **Warning** to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

### **Minimum valid pressure — Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

#### **Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to **Warning**.

## **Version History**

**Introduced in R2006b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

[Fixed-Displacement Motor](#) | [Variable-Displacement Pump](#) | [Variable-Displacement Motor](#) | [Fixed-Displacement Pump \(TL\)](#) | [Fixed-Displacement Motor \(TL\)](#)

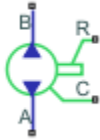
## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Fixed-Displacement Pump (IL)

Fixed-displacement pump in isothermal liquid system

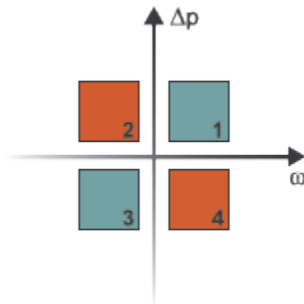
**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors



### Description

The Fixed-Displacement Pump (IL) block models a pump with constant-volume displacement. The fluid may move from port **A** to port **B**, called *forward mode*, or from port **B** to port **A**, called *reverse mode*. Pump mode operation occurs when there is a pressure gain in the direction of the flow. Motor mode operation occurs when there is a pressure drop in the direction of the flow.

Shaft rotation corresponds to the sign of the fluid volume. Positive fluid displacement corresponds to positive shaft rotation in forward mode. Negative fluid displacement corresponds to negative shaft angular velocity in forward mode.



### Operation Modes

The block has four modes of operation. The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$  and the angular velocity,  $\omega = \omega_R - \omega_C$ :

- Mode 1, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**.
- Mode 2, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- Mode 3, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.
- Mode 4, *Forward Motor*: Flow from port **A** to **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.



The pump block has analytical, lookup table, and physical signal parameterizations. When using tabulated data or an input signal for parameterization, you can choose to characterize pump operation based on efficiency or losses.

The threshold parameters **Pressure gain threshold for pump-motor transition** and **Angular velocity threshold for pump-motor transition** identify regions where numerically smoothed flow transition between the pump operational modes can occur. For the pressure and angular velocity thresholds, choose a transition region that provides some margin for the transition term, but which is small enough relative to the typical pump pressure gain and angular velocity so that it will not impact calculation results.

### Analytical Leakage and Friction Parameterization

If you set **Leakage and friction parameterization** to **Analytical**, the block calculates leakage and friction from constant values of shaft velocity, pressure gain, and friction torque. The leakage flow rate, which is correlated with the pressure differential over the pump, is calculated as:

$$\dot{m}_{leak} = K\rho_{avg}\Delta p,$$

where:

- $\Delta p$  is  $p_B - p_A$ .
- $\rho_{avg}$  is the average fluid density.
- $K$  is the Hagen-Poiseuille coefficient for analytical loss,

$$K = \frac{D\omega_{nom}(1 - \eta_{v, nom})}{\Delta p_{nom}},$$

where:

- $D$  is the **Displacement**.
- $\omega_{nom}$  is the **Nominal shaft angular velocity**.
- $\eta_{v, nom}$  is the **Volumetric efficiency at nominal conditions**.
- $\Delta p_{nom}$  is the **Nominal pressure gain**.

The friction torque, which is related to the pump pressure differential, is calculated as:

$$\tau_{fr} = (\tau_0 + k|\Delta p|)\tanh\left(\frac{4\omega}{5 \times 10^{-5}\omega_{nom}}\right),$$

where:

- $\tau_0$  is the **No-load torque**.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_{m, nom}$ :

$$k = \frac{\tau_{fr, nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr, nom}$  is the friction torque at nominal conditions:

$$\tau_{fr, nom} = \left(\frac{1 - \eta_{m, nom}}{\eta_{m, nom}}\right)D\Delta p_{nom}.$$

- $\omega$  is the relative shaft angular velocity, or  $\omega_R - \omega_C$ .

### Tabulated Data Parameterizations

When using tabulated data for pump efficiencies or losses, you can provide data for one or more of the pump operational modes. The signs of the tabulated data determine the operational regime of the block. When data is provided for less than four operational modes, the block calculates the complementing data for the other mode(s) by extending the given data into the remaining quadrants.

#### The Tabulated data - volumetric and mechanical efficiencies parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \dot{m}_{leak, pump} \left( \frac{1 + \alpha}{2} \right) + \dot{m}_{leak, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\dot{m}_{leak, pump} = (1 - \eta_v) \dot{m}_{ideal}$
- $\dot{m}_{leak, motor} = (\eta_v - 1) \dot{m}$

and  $\eta_v$  is the volumetric efficiency, which is interpolated from the user-provided tabulated data. The transition term,  $\alpha$ , is

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{threshold}}\right) \tanh\left(\frac{4\omega}{\omega_{threshold}}\right),$$

where:

- $\Delta p$  is  $p_B - p_A$ .
- $p_{threshold}$  is the **Pressure gain threshold for pump-motor transition**.
- $\omega$  is  $\omega_R - \omega_C$ .
- $\omega_{threshold}$  is the **Angular velocity threshold for pump-motor transition**.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{fr, pump} \left( \frac{1 + \alpha}{2} \right) + \tau_{fr, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\tau_{fr, pump} = (1 - \eta_m) \tau$
- $\tau_{fr, motor} = (\eta_m - 1) \tau_{ideal}$

and  $\eta_m$  is the mechanical efficiency, which is interpolated from the user-provided tabulated data.

#### The Tabulated data - volumetric and mechanical losses parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{loss}(\Delta p, \omega),$$

where  $q_{loss}$  is interpolated from the **Volumetric loss table,  $q\_loss(dp, w)$**  parameter, which is based on user-supplied data for pressure drop, shaft angular velocity, and fluid volumetric displacement.

The shaft friction torque is calculated as:

$$\tau_{fr} = \tau_{loss}(\Delta p, \omega),$$

where  $\tau_{loss}$  is interpolated from the **Mechanical loss table, torque\_loss(dp,w)** parameter, which is based on user-supplied data for pressure drop and shaft angular velocity.

### Input Signal Parameterization

When you select **Input signal - volumetric and mechanical efficiencies**, ports **EV** and **EM** are enabled. The internal leakage and shaft friction are calculated in the same way as the **Tabulated data - volumetric and mechanical efficiencies** parameterization, except that  $\eta_v$  and  $\eta_m$  are received directly at ports **EV** and **EM**, respectively.

When you select **Input signal - volumetric and mechanical losses**, ports **LV** and **LM** are enabled. These ports receive leakage flow and friction torque as positive physical signals. The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{LV} \tanh\left(\frac{4\Delta p}{p_{thresh}}\right),$$

where:

- $q_{LV}$  is the leakage flow received at port **LV**.
- $p_{thresh}$  is the **Pressure gain threshold for pump-motor transition** parameter.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{LM} \tanh\left(\frac{4\omega}{\omega_{thresh}}\right),$$

where

- $\tau_{LM}$  is the friction torque received at port **LM**.
- $\omega_{thresh}$  is the **Angular velocity threshold for pump-motor transition** parameter.

The volumetric and mechanical efficiencies range between the user-defined specified minimum and maximum values. Any values lower or higher than this range will take on the minimum and maximum specified values, respectively.

### Pump Operation

The pump flow rate is:

$$\dot{m} = \dot{m}_{ideal} - \dot{m}_{leak},$$

where  $\dot{m}_{ideal} = \rho_{avg} D \cdot \omega$ .

The pump torque is:

$$\tau = \tau_{ideal} + \tau_{fr},$$

where  $\tau_{ideal} = D \cdot \Delta p$ .

The mechanical power delivered by the pump shaft is:

$$\varphi_{mech} = \tau\omega,$$

and the pump hydraulic power is:

$$\varphi_{hyd} = \frac{\Delta p \dot{m}}{\rho_{avg}}.$$

If you would like to know if the block is operating beyond the supplied tabulated data, you can set **Check if operating beyond the quadrants of supplied tabulated data** to `Warning` to receive a warning if this occurs, or `Error` to stop the simulation when this occurs. For parameterization by input signal for volumetric or mechanical losses, you can be notified if the simulation surpasses operating modes with the **Check if operating beyond pump mode** parameter.

You can also monitor pump functionality. Set **Check if pressures are less than pump minimum pressure** to `Warning` to receive a warning if this occurs, or `Error` to stop the simulation when this occurs.

### Predefined Parameterization

Pre-parameterization of the Fixed-Displacement Pump (IL) block with manufacturer data is available. This data allows you to model a specific supplier component.

To load a predefined parameterization,

- 1 Click the "Select a predefined parameterization" hyperlink in the Fixed-Displacement Pump (IL) block dialog description.
- 2 Select a part from the drop-down menu and click **Update block with selected part**.
- 3 If you change any parameter settings after loading a parameterization, you can check your changes by clicking **Compare block settings with selected part**. Any difference in settings between the block and pre-defined parameterization will display in the MATLAB command window.

---

**Note** Predefined parameterizations of Simscape components use available data sources for supplying parameter values. Engineering judgement and simplifying assumptions are used to fill in for missing data. As a result, deviations between simulated and actual physical behavior should be expected. To ensure requisite accuracy, you should validate simulated behavior against experimental data and refine component models as necessary.

---

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry or exit port to the pump.

#### B — Liquid port

isothermal liquid

Liquid entry or exit port to the pump.

**R – Mechanical port**

mechanical rotational

Rotating shaft angular velocity and torque.

**C – Mechanical port**

mechanical rotational

Pump casing angular velocity and torque.

**Input****EV – Volumetric efficiency**

physical signal

Pump efficiency for fluid displacement, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**EM – Mechanical efficiency**

physical signal

Pump efficiency for the mechanical supply of energy, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**LV – Leakage flow rate, m<sup>3</sup>/s**

physical signal

Pump volumetric losses in m<sup>3</sup>/s, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**LM – Friction torque, N\*m**

physical signal

Pump mechanical losses in N\*m, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Parameters

### Leakage and friction parameterization — Method of calculating leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Parameterization of the leakage and friction characteristics of the pump.

- In the **Analytical** parameterization, the leakage flow rate and the friction torque are calculated by analytical equations.
- In the **Tabulated data - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are calculated from the user-supplied **Pressure gain vector,  $dp$**  and **Shaft angular velocity vector,  $w$**  parameters and interpolated from the 2-D dependent **Volumetric efficiency table,  $e_v(dp,w)$**  and **Mechanical efficiency table,  $e_m(dp,w)$**  tables.
- In the **Tabulated data - volumetric and mechanical loss** parameterization, the leakage flow rate and friction torque are calculated from the user-supplied **Pressure gain vector,  $dp$**  and **Shaft angular velocity vector,  $w$**  parameters and interpolated from the 2-D dependent **Volumetric loss table,  $q_{loss}(dp,w)$**  and **Mechanical loss table,  $torque_{loss}(dp,w)$**  tables.
- In the **Input signal - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are received as physical signals at ports **EV** and **EM**, respectively.
- In the **Input signal - volumetric and mechanical loss** parameterization, the leakage flow rate and torque friction are received as physical signals at ports **LV** and **LM**, respectively.

### Displacement — Fixed-volume fluid displacement

30 cm<sup>3</sup>/rev (default) | scalar

Amount of fluid displaced by shaft rotating under nominal or typical operating conditions.

### Nominal shaft angular velocity — Shaft angular velocity

188 rad/s (default) | scalar

Angular velocity of the shaft under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Nominal pressure gain — Pressure gain between fluid entry and exit

10 MPa (default) | scalar

Pump pressure gain between the fluid entry and exit under nominal or typical operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Volumetric efficiency at nominal conditions — Ratio of actual flow rate to ideal flow rate

0.92 (default) | positive scalar in the range of (0,1]

Ratio of actual flow rate to ideal flow rate at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Baseline torque**

0 N\*m (default) | scalar

Minimum value of torque to overcome seal friction and induce shaft motion.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of actual torque to ideal torque generated**

0.88 (default) | positive scalar

Ratio of actual torque to ideal torque generated at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Pressure gain vector, dp – Vector of pressure data for tabulated data parameterization**

[.1, 1, 2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** parameter for the 2-D dependent **Volumetric efficiency table, e\_v(dp,w)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Shaft angular velocity vector, w – Vector of angular velocity data for tabulated data parameterization**

[25, 50, 100, 200, 300, 400] rad/s (default) | 1-by-n vector

Vector of angular velocity data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** parameter for the 2-D dependent **Volumetric efficiency table, e\_v(dp,w)** and **Mechanical efficiency table, e\_m(dp,w)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Volumetric efficiency table,  $e_v(dp,w)$  — Volumetric efficiency for tabulated data parameterization**

[.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91] (default) |  $M$ -by- $N$ -by- $P$  matrix

$M$ -by- $N$  matrix of volumetric efficiencies at the specified fluid pressure gain and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  — Mechanical efficiency for tabulated data parameterization**

[.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984] (default) |  $M$ -by- $N$ -by- $P$  matrix

$M$ -by- $N$  matrix of mechanical efficiencies at the specified fluid pressure gain and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric loss table,  $q_{loss}(dp,w)$  — Volumetric losses for tabulated data parameterization**

[.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] \*  $1e-3$  m<sup>3</sup>/s (default) |  $M$ -by- $N$ -by- $P$  matrix

$M$ -by- $N$  matrix of volumetric efficiencies at the specified fluid pressure gain and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical loss.

**Mechanical loss table,  $torque_{loss}(dp,w)$  — Mechanical losses for tabulated data parameterization**

[.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505; .1937, .1937, .1833, .1833, .1729, .1626] N\*m (default) |  $M$ -by- $N$ -by- $P$  matrix



$M$ -by- $N$  matrix of mechanical losses at the specified fluid pressure gain and shaft angular velocity. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical loss.

#### Minimum volumetric efficiency – Minimum value of volumetric efficiency

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of volumetric efficiency. If the input signal is below this value, the volumetric efficiency is set to the minimum volumetric efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Maximum volumetric efficiency – Maximum value of volumetric efficiency

1 (default) | positive scalar in the range of (0,1]

Maximum value of volumetric efficiency. If the input signal is above this value, the volumetric efficiency is set to the maximum volumetric efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Minimum mechanical efficiency – Minimum value of mechanical efficiency

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of mechanical efficiency. If the input signal is below this value, the mechanical efficiency is set to the minimum mechanical efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Maximum mechanical efficiency – Maximum value of mechanical efficiency

1 (default) | positive scalar in the range of (0,1]

Maximum value of mechanical efficiency. If the input signal is above this value, the mechanical efficiency is set to the maximum mechanical efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure gain threshold for pump-motor transition — Pressure threshold for mode transition**

1e-3 MPa (default) | positive scalar

Threshold pressure gain value for the transition between pump and motor functionality. A transition region is defined around 0 MPa between the positive and negative values of the pressure gain threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Angular velocity threshold for pump-motor transition — Angular velocity threshold for mode transition**

10 rad/s (default) | positive scalar

Threshold angular velocity value for the transition between pump and motor functionality. A transition region is defined around 0 rad/s between the positive and negative values of the angular velocity threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Check if operating beyond the quadrants of supplied tabulated data — Whether to notify if extents of supplied data are surpassed**

None (default) | Warning | Error

Whether to notify if the extents of the supplied data are surpassed. Select Warning to be notified when the block uses values beyond the supplied data range. Select Error to stop the simulation when the block uses values beyond the supplied data range.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating outside of pump mode — Whether to notify if block operates outside of the pump mode functionality**

None (default) | Warning | Error

Whether to notify if block operates outside of the pump mode functionality. This block has four operation modes: forward pump, reverse pump, reverse motor, and forward motor. Select **Warning** to be notified when the block operates in the forward or reverse motor modes. Select **Error** to stop the simulation when the block operates in the forward or reverse motor modes.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical losses`.

#### Check if pressures are less than pump minimum pressure — Whether to notify if fluid exit pressure is low

None (default) | Warning | Error

Whether to notify if the fluid at port **A** or **B** experiences low pressure. Select **Warning** to be notified when the outlet pressure falls below a minimum specified value. Select **Error** to stop the simulation when the outlet pressure falls below a minimum specified value.

The parameter helps to identify potential conditions for cavitation, when the fluid pressure falls below the fluid vapor pressure.

#### Pump minimum pressure — Lower threshold to acceptable pressure at the pump outlet

0.101325 MPa (default) | positive scalar

Lower threshold of acceptable pressure at the pump inlet and outlet.

#### Dependencies

To enable this parameter, set **Check if pressures are less than pump minimum pressure** to:

- Warning
- Error

## Version History

Introduced in R2020a

## Extended Capabilities

#### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Variable-Displacement Pump (IL) | Fixed-Displacement Pump (TL) | Pressure-Compensated Pump (IL) | Fixed-Displacement Motor (IL)

## Fixed-Displacement Pump (TL)

Mechanical-hydraulic power conversion device

**Library:** Simscape / Fluids / Thermal Liquid / Pumps & Motors



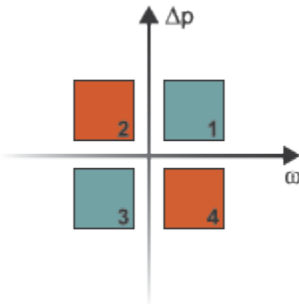
### Description

The Fixed-Displacement Pump (TL) block represents a pump that extracts power from a mechanical rotational network and delivers it to a thermal liquid network. The pump displacement is fixed at a constant value that you specify through the **Displacement** parameter.

Ports **A** and **B** represent the pump inlets. Ports **R** and **C** represent the drive shaft and case. During normal operation, the pressure gain from port **A** to port **B** is positive if the angular velocity at port **R** relative to port **C** is positive.

### Operating Modes

The block has four modes of operation, as shown by this image.



The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$  and the angular velocity,  $\omega = \omega_R - \omega_C$ :

- The quadrant labeled **1** represents the forward pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**
- The quadrant labeled **2** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- The quadrant labeled **3** represents the reverse pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**
- The quadrant labeled **4** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.

The response time of the pump is negligible in comparison with the system response time. The pump reaches steady state nearly instantaneously and is treated as a quasi-steady component.

### Energy Balance

The block associates the mechanical work done by the pump with an energy exchange. The governing energy balance equation is

$$\phi_A + \phi_B + P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are the energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is the pump hydraulic power, which is a function of the pressure difference between the pump ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$ .

The block generates mechanical power due to torque,  $\tau$ , and angular velocity,  $\omega$ :

$$P_{mech} = \tau\omega.$$

### Flow Rate and Driving Torque

The mass flow rate generated at the pump is

$$\dot{m} = \dot{m}_{Ideal} - \dot{m}_{Leak},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{Ideal}$  is the ideal mass flow rate.
- $\dot{m}_{Leak}$  is the internal leakage mass flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{Ideal} + \tau_{Friction},$$

where:

- $\tau$  is the actual driving torque.
- $\tau_{Ideal}$  is the ideal driving torque.
- $\tau_{Friction}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal mass flow rate is

$$\dot{m}_{Ideal} = \rho D\omega,$$

and the ideal required torque is

$$\tau_{Ideal} = D\Delta p,$$

where:

- $\rho$  is the average of the fluid densities at thermal liquid ports **A** and **B**.
- $D$  is the **Displacement** parameter.

- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure gain from inlet to outlet.

### Leakage and Friction Parameterization

You can parameterize leakage and friction analytically, by using tabulated efficiencies or losses, or by using input efficiencies or input losses.

#### Analytical

When you set the **Leakage and friction parameterization** parameter to `Analytical`, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}}\rho_{\text{Avg}}\Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}}|\Delta p| \tanh\left(\frac{4\omega}{(5 \cdot 10^{-5})\omega_{\text{Nom}}}\right) \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. The block computes this coefficient from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the fluid, which is the average of the values at the ports.
- $K_{\text{TP}}$  is the friction torque vs. pressure gain coefficient at nominal displacement, which the block determines from the **Mechanical efficiency at nominal conditions** parameter,  $\eta_m$ :

$$k = \frac{\tau_{fr, nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr, nom}$  is the friction torque at nominal conditions:

$$\tau_{fr, nom} = \left( \frac{1 - \eta_{m, nom}}{\eta_{m, nom}} \right) D \Delta p_{nom}.$$

- $\Delta p_{\text{Nom}}$  is the value of the **Nominal pressure gain** parameter. This value is the pressure gain at which the nominal volumetric efficiency is specified.
- $\tau_0$  is the value of the **No-load torque** parameter.
- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter.

The block determines the Hagen-Poiseuille coefficient from the nominal fluid and component parameters

$$K_{\text{HP}} = \frac{D\omega_{\text{Nom}}\mu_{\text{Nom}}(1 - \eta_{v, \text{Nom}})}{\Delta p_{\text{Nom}}},$$

where:

- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter. This value is the angular velocity at which the block specifies the nominal volumetric efficiency.

- $\mu_{\text{Nom}}$  is the value of the **Nominal Dynamic viscosity** parameter. This value is the dynamic viscosity at which the block specifies the nominal volumetric efficiency.
- $\eta_{\text{v,Nom}}$  is the value of the **Volumetric efficiency at nominal conditions** parameter. This is the volumetric efficiency that corresponds to the specified nominal conditions.

### Tabulated Efficiencies

When you set the **Leakage and friction parameterization** parameter to Tabulated data - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \dot{m}_{\text{Leak,Pump}} \frac{(1 + \alpha)}{2} + \dot{m}_{\text{Leak,Motor}} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{\text{Friction}} = \tau_{\text{Friction,Pump}} \frac{1 + \alpha}{2} + \tau_{\text{Friction,Motor}} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\dot{m}_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.

This hyperbolic function describes the smoothing parameter  $\alpha$

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the value of the **Pressure gain threshold for motor-pump transition** parameter.
- $\omega_{\text{Threshold}}$  is the value of the **Angular velocity threshold for motor-pump transition** parameter.

The block calculates the leakage flow rate from the volumetric efficiency, which the **Volumetric efficiency table** parameter specifies over the  $\Delta p$ - $\omega$  domain. When operating in pump mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = (1 - \eta_{\text{v}})\dot{m}_{\text{Ideal}},$$

where  $\eta_{\text{v}}$  is the volumetric efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = -(1 - \eta_{\text{v}})\dot{m}.$$

The block calculates the friction torque from the mechanical efficiency, which the **Mechanical efficiency table** parameter specifies over the  $\Delta p$ - $\omega$  domain. When operating in pump mode, the friction torque is

$$\tau_{\text{Friction,Pump}} = (1 - \eta_{\text{m}})\tau,$$

where  $\eta_m$  is the mechanical efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the friction torque is

$$\tau_{\text{Friction, Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}}.$$

### Tabulated Losses

When you set the **Leakage and friction parameterization** parameter to **Tabulated data - volumetric and mechanical losses**, the block specifies the leakage volumetric flow rate in tabulated form over the  $\Delta p$ - $\omega$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega).$$

The block calculates the mass flow rate due to leakage from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The block calculates the friction torque in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega),$$

where  $q_{\text{Leak}}(\Delta p, \omega)$  and  $\tau_{\text{Friction}}(\Delta p, \omega)$  are the volumetric and mechanical losses, specified through interpolation or extrapolation of the tabulated data in the **Volumetric loss table** and **Mechanical loss table** parameters.

### Input Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The block replaces the volumetric and mechanical efficiency lookup tables with the physical signal input ports **EV** and **EM**.

The efficiencies are positive quantities with values between 0 and 1. The block sets input values outside of these bounds to 0 for inputs smaller than 0 or 1 for inputs greater than 1. The block saturates the efficiency signals at the value of the **Minimum volumetric efficiency** or **Minimum mechanical efficiency** parameter and the **Maximum volumetric efficiency** or **Maximum mechanical efficiency** parameter.

### Input Losses

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical losses**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The block replaces the volumetric and mechanical loss lookup tables with the physical signal input ports **LV** and **LM**.

The block expects the inputs to be positive and sets the signs automatically from the  $\Delta p$ - $\omega$  quadrant where the component is operating. If you provide a negative signal, the block returns zero losses.

### Assumptions and Limitations

- The block treats the pump as a quasi-steady component.
- The block ignores the effects of fluid inertia and elevation.
- The pump wall is rigid.



- The block ignores external leakage.

## Ports

### Input

#### **EV – Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **EM – Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **LV – Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss which is the internal leakage flow rate between the pump inlets.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

#### **LM – Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss which is the friction torque on the rotating pump shaft.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Conserving

#### **A – Pump inlet**

thermal liquid

Thermal liquid conserving port associated with the pump inlet.

**B – Pump outlet**

thermal liquid

Thermal liquid conserving port associated with the pump outlet.

**C – Pump case**

mechanical rotational

Mechanical rotational conserving port associated with the pump case.

**R – Pump shaft**

mechanical rotational

Mechanical rotational conserving port associated with the rotational pump shaft.

**Parameters****Leakage and friction parameterization – Parameterization of leakage flow rate and friction torque**

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute the flow-rate and torque losses due to internal leaks and friction. Use the Analytical if the block parameters are generally available from component data sheets. When you select Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses, the block uses lookup tables to map pressure gains and shaft angular velocities to component efficiencies or losses.

When you select Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses, the block performs the leakage flow rate and friction torque calculations the same as the Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses settings, respectively. When you select Input signal - volumetric and mechanical efficiencies, the block enables the **EV** and **EM** ports. You use these ports to specify the volumetric and mechanical efficiency. When you select Input signal - volumetric and mechanical losses, the block enables the **LV** and **LM** ports. You use these ports to specify the volumetric and mechanical losses.

**Displacement – Fluid volume displaced per shaft rotation**

30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid volume displaced per shaft rotation. The block maintains this value throughout the simulation.

**Nominal shaft angular velocity – Shaft angular velocity for given volumetric efficiency**

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal pressure gain — Pressure gain for corresponding volumetric efficiency**

10 MPa (default) | scalar

Pressure gain that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal dynamic viscosity — Dynamic viscosity at which to specify the volumetric efficiency**

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Volumetric efficiency at nominal conditions — Volumetric efficiency at specified nominal conditions**

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions — Ratio of ideal-to-actual mechanical power**

0.88 (default) | positive scalar

Ratio of ideal mechanical power to actual mechanical power at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque — Minimum torque required to induce shaft rotation**

0 N\*m (default) | scalar

Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Pressure gain vector,  $dp$  — Pressure gains for given volumetric and mechanical efficiencies or losses**

[.1, 1, 2] MPa (default) | vector

Pressure gains for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Shaft angular velocity vector,  $w$  — Angular velocities at which to specify volumetric and mechanical efficiencies or losses**

[25, 50, 100, 200, 300, 400] rad/s (default) | vector

Shaft angular velocities for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Volumetric efficiency table,  $e_v(dp,w)$  — Volumetric efficiencies for given pressure gains and angular velocities**

[.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91] (default) | matrix

Volumetric efficiencies for the given fluid pressure gains and shaft angular velocities. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  — Mechanical efficiencies for given pressure gains and angular velocities**

[.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984] (default) | matrix

Mechanical efficiencies for the given fluid pressure gains and shaft angular velocities. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Volumetric loss table, $q_{\text{loss}}(dp, w)$ – Internal leakage flow rates for corresponding pressure gains and angular velocities

[.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] \* 1e-3 m<sup>3</sup>/s (default) | matrix

Volumetric losses at the specified fluid pressure gains and shaft angular velocities. Volumetric loss is the internal leakage volumetric flow rate between port **A** and port **B**.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

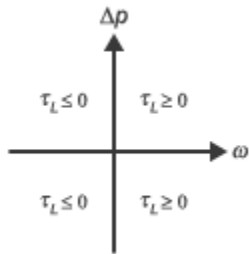
#### Mechanical loss table, $\text{torque}_{\text{loss}}(dp, w)$ – Friction torques for corresponding pressure gains and angular velocities

[.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505; .1937, .1937, .1833, .1833, .1729, .1626] N\*m (default) | matrix

Mechanical losses for the given pressure gains and shaft angular velocities. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-862 for the operation modes corresponding to parameter specifications and the resulting quadrants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

### Minimum volumetric efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum volumetric efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Minimum mechanical efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum mechanical efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Pressure gain threshold for motor-pump transition — Pressure gain at which to initiate smooth transition between motor and pump modes

1e-3 MPa (default) | scalar

Pressure gain from the inlet to the outlet below which the block begins to transition between the motor and pump modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

#### Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate smooth transition between pump and motor modes

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between the motor and pump modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

#### Cross-sectional area at ports A and B — Flow area at component inlet and outlet

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

#### Check if operating beyond the quadrants of supplied tabulated data — Simulation warning mode for operating conditions outside range of tabulated data

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the range of tabulated data. If you select Warning, the block generates a warning when the fluid pressure gain or the shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop. If you select Error, the simulation will stop for conditions outside the range of tabulated data.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating outside of pump mode — Simulation warning mode for operating conditions outside pump mode**

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the pump mode. When you set this parameter to **Warning**, the block generates a warning if the pump transitions to motoring mode. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the pump mode.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Version History**

Introduced in R2016a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

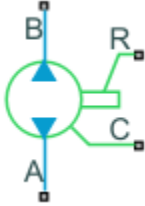
Centrifugal Pump (TL) | Fixed-Displacement Motor (TL) | Variable-Displacement Pump (TL)



## Fixed-Displacement Pump (2P)

Mechanical-hydraulic power conversion device

**Library:** Simscape / Fluids / Two-Phase Fluid / Fluid Machines



### Description

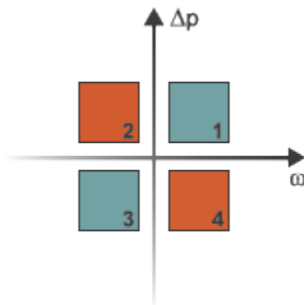
The Fixed-Displacement Pump (2P) block represents a pump that extracts power from a mechanical rotational network and delivers it to a two-phase fluid network. The pump displacement is fixed at a constant value that you specify through the **Displacement** parameter.

Ports **A** and **B** represent the pump inlets. Ports **R** and **C** represent the drive shaft and case. During normal operation, the pressure gain from port **A** to port **B** is positive if the angular velocity at port **R** relative to port **C** is positive.

The Fixed-Displacement Pump (2P) block assumes that liquid enters the pump inlet. You can use the **Report when fluid is not fully liquid** parameter to choose what the block does when the fluid does not meet liquid conditions. To move vapor in a two-phase fluid network, use a compressor.

### Operating Modes

The block has four modes of operation, as shown by this image.



The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$  and the angular velocity,  $\omega = \omega_R - \omega_C$ :

- The quadrant labeled **1** represents the forward pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**
- The quadrant labeled **2** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- The quadrant labeled **3** represents the reverse pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**

- The quadrant labeled **4** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.

The response time of the pump is negligible in comparison with the system response time. The pump reaches steady state nearly instantaneously and is treated as a quasi-steady component.

### Energy Balance

The block associates the mechanical work done by the pump with an energy exchange. The governing energy balance equation is

$$\phi_A + \phi_B + P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are the energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is the pump hydraulic power, which is a function of the pressure difference between the pump ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$ .

The block generates mechanical power due to torque,  $\tau$ , and angular velocity,  $\omega$ :

$$P_{mech} = \tau \omega .$$

### Flow Rate and Driving Torque

The mass flow rate generated at the pump is

$$\dot{m} = \dot{m}_{Ideal} - \dot{m}_{Leak},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{Ideal}$  is the ideal mass flow rate.
- $\dot{m}_{Leak}$  is the internal leakage mass flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{Ideal} + \tau_{Friction},$$

where:

- $\tau$  is the actual driving torque.
- $\tau_{Ideal}$  is the ideal driving torque.
- $\tau_{Friction}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal mass flow rate is

$$\dot{m}_{Ideal} = \rho D \omega,$$

and the ideal required torque is

$$\tau_{Ideal} = D \Delta p,$$

where:

- $\rho$  is the average of the fluid densities at ports **A** and **B**.
- $D$  is the **Displacement** parameter.
- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure gain from inlet to outlet.

### Leakage and Friction Parameterization

You can parameterize leakage and friction analytically, by using tabulated efficiencies or losses, or by using input efficiencies or input losses.

#### Analytical

When you set the **Leakage and friction parameterization** parameter to `Analytical`, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}}\rho_{\text{Avg}}\Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}}|\Delta p| \tanh\left(\frac{4\omega}{(5 \cdot 10^{-5})\omega_{\text{Nom}}}\right) \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. The block computes this coefficient from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the fluid, which is the average of the values at the ports.
- $K_{\text{TP}}$  is the friction torque vs. pressure gain coefficient at nominal displacement, which the block determines from the **Mechanical efficiency at nominal conditions** parameter,  $\eta_m$ :

$$k = \frac{\tau_{fr, nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr, nom}$  is the friction torque at nominal conditions:

$$\tau_{fr, nom} = \left( \frac{1 - \eta_{m, nom}}{\eta_{m, nom}} \right) D \Delta p_{nom}.$$

- $\Delta p_{\text{Nom}}$  is the value of the **Nominal pressure gain** parameter. This value is the pressure gain at which the nominal volumetric efficiency is specified.
- $\tau_0$  is the value of the **No-load torque** parameter.
- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter.

The block determines the Hagen-Poiseuille coefficient from the nominal fluid and component parameters

$$K_{\text{HP}} = \frac{D\omega_{\text{Nom}}\mu_{\text{Nom}}(1 - \eta_{v, \text{Nom}})}{\Delta p_{\text{Nom}}},$$

where:

- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter. This value is the angular velocity at which the block specifies the nominal volumetric efficiency.
- $\mu_{\text{Nom}}$  is the value of the **Nominal Dynamic viscosity** parameter. This value is the dynamic viscosity at which the block specifies the nominal volumetric efficiency.
- $\eta_{v,\text{Nom}}$  is the value of the **Volumetric efficiency at nominal conditions** parameter. This is the volumetric efficiency that corresponds to the specified nominal conditions.

### Tabulated Efficiencies

When you set the **Leakage and friction parameterization** parameter to Tabulated data - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \dot{m}_{\text{Leak,Pump}} \frac{(1 + \alpha)}{2} + \dot{m}_{\text{Leak,Motor}} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{\text{Friction}} = \tau_{\text{Friction,Pump}} \frac{1 + \alpha}{2} + \tau_{\text{Friction,Motor}} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\dot{m}_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.

This hyperbolic function describes the smoothing parameter  $\alpha$

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the value of the **Pressure gain threshold for motor-pump transition** parameter.
- $\omega_{\text{Threshold}}$  is the value of the **Angular velocity threshold for motor-pump transition** parameter.

The block calculates the leakage flow rate from the volumetric efficiency, which the **Volumetric efficiency table** parameter specifies over the  $\Delta p$ - $\omega$  domain. When operating in pump mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = (1 - \eta_v)\dot{m}_{\text{Ideal}},$$

where  $\eta_v$  is the volumetric efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = -(1 - \eta_v)\dot{m}.$$

The block calculates the friction torque from the mechanical efficiency, which the **Mechanical efficiency table** parameter specifies over the  $\Delta p$ - $\omega$  domain. When operating in pump mode, the friction torque is

$$\tau_{\text{Friction,Pump}} = (1 - \eta_m)\tau,$$

where  $\eta_m$  is the mechanical efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the friction torque is

$$\tau_{\text{Friction,Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}}.$$

### Tabulated Losses

When you set the **Leakage and friction parameterization** parameter to **Tabulated data - volumetric and mechanical losses**, the block specifies the leakage volumetric flow rate in tabulated form over the  $\Delta p$ - $\omega$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega).$$

The block calculates the mass flow rate due to leakage from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The block calculates the friction torque in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega),$$

where  $q_{\text{Leak}}(\Delta p, \omega)$  and  $\tau_{\text{Friction}}(\Delta p, \omega)$  are the volumetric and mechanical losses, specified through interpolation or extrapolation of the tabulated data in the **Volumetric loss table** and **Mechanical loss table** parameters.

### Input Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The block replaces the volumetric and mechanical efficiency lookup tables with the physical signal input ports **EV** and **EM**.

The efficiencies are positive quantities with values between 0 and 1. The block sets input values outside of these bounds to 0 for inputs smaller than 0 or 1 for inputs greater than 1. The block saturates the efficiency signals at the value of the **Minimum volumetric efficiency** or **Minimum mechanical efficiency** parameter and the **Maximum volumetric efficiency** or **Maximum mechanical efficiency** parameter.

### Input Losses

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical losses**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The block replaces the volumetric and mechanical loss lookup tables with the physical signal input ports **LV** and **LM**.

The block expects the inputs to be positive and sets the signs automatically from the  $\Delta p$ - $\omega$  quadrant where the component is operating. If you provide a negative signal, the block returns zero losses.

### Assumptions and Limitations

- The block treats the pump as a quasi-steady component.

- The block ignores the effects of fluid inertia and elevation.
- The pump wall is rigid.
- The block ignores external leakage.

## Ports

### Input

#### **EV – Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **EM – Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### **LV – Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss which is the internal leakage flow rate between the pump inlets.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

#### **LM – Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss which is the friction torque on the rotating pump shaft.

#### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Conserving****A – Pump inlet**

two-phase fluid

Two-phase fluid conserving port associated with the pump inlet.

**B – Pump outlet**

two-phase fluid

Two-phase fluid conserving port associated with the pump outlet.

**C – Pump case**

mechanical rotational

Mechanical rotational conserving port associated with the pump case.

**R – Pump shaft**

mechanical rotational

Mechanical rotational conserving port associated with the rotational pump shaft.

**Parameters****Leakage and friction parameterization – Parameterization of leakage flow rate and friction torque**

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute the flow-rate and torque losses due to internal leaks and friction. Use the Analytical if the block parameters are generally available from component data sheets. When you select Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses, the block uses lookup tables to map pressure gains and shaft angular velocities to component efficiencies or losses.

When you select Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses, the block performs the leakage flow rate and friction torque calculations the same as the Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses settings, respectively. When you select Input signal - volumetric and mechanical efficiencies, the block enables the **EV** and **EM** ports. You use these ports to specify the volumetric and mechanical efficiency. When you select Input signal - volumetric and mechanical losses, the block enables the **LV** and **LM** ports. You use these ports to specify the volumetric and mechanical losses.

**Displacement – Fluid volume displaced per shaft rotation**30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid volume displaced per shaft rotation. The block maintains this value throughout the simulation.

**Nominal shaft angular velocity – Shaft angular velocity for given volumetric efficiency**

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal pressure gain – Pressure gain for corresponding volumetric efficiency**

10 MPa (default) | scalar

Pressure gain that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal dynamic viscosity – Dynamic viscosity at which to specify the volumetric efficiency**

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Volumetric efficiency at nominal conditions – Volumetric efficiency at specified nominal conditions**

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of ideal-to-actual mechanical power**

0.88 (default) | positive scalar

Ratio of ideal mechanical power to actual mechanical power at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Minimum torque required to induce shaft rotation**

0 N\*m (default) | scalar



Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Pressure gain vector, $dp$ – Pressure gains for given volumetric and mechanical efficiencies or losses

[.1, 1, 2] MPa (default) | vector

Pressure gains for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

#### Shaft angular velocity vector, $w$ – Angular velocities at which to specify volumetric and mechanical efficiencies or losses

[25, 50, 100, 200, 300, 400] rad/s (default) | vector

Shaft angular velocities for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

#### Volumetric efficiency table, $e_v(dp,w)$ – Volumetric efficiencies for given pressure gains and angular velocities

[.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91] (default) | matrix

Volumetric efficiencies for the given fluid pressure gains and shaft angular velocities. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w)$  — Mechanical efficiencies for given pressure gains and angular velocities**

[.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984] (default) | matrix

Mechanical efficiencies for the given fluid pressure gains and shaft angular velocities. The efficiencies must be in the range (0,1].  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric loss table,  $q_{loss}(dp,w)$  — Internal leakage flow rates for corresponding pressure gains and angular velocities**

[.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] \*  $1e-3$  m<sup>3</sup>/s (default) | matrix

Volumetric losses at the specified fluid pressure gains and shaft angular velocities. Volumetric loss is the internal leakage volumetric flow rate between port **A** and port **B**.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

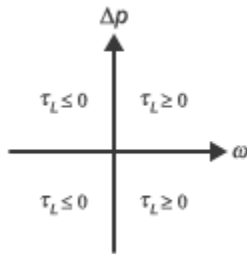
**Mechanical loss table,  $torque_{loss}(dp,w)$  — Friction torques for corresponding pressure gains and angular velocities**

[.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505; .1937, .1937, .1833, .1833, .1729, .1626] N\*m (default) | matrix

Mechanical losses for the given pressure gains and shaft angular velocities. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.

Specify the data for a single quadrant,  $(\omega, \Delta p)$ . Refer to “Operating Modes” on page 1-875 for the operation modes corresponding to parameter specifications and the resulting quadrants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

### Minimum volumetric efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum volumetric efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Minimum mechanical efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum mechanical efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure gain threshold for motor-pump transition — Pressure gain at which to initiate smooth transition between motor and pump modes**

1e-3 MPa (default) | scalar

Pressure gain from the inlet to the outlet below which the block begins to transition between the motor and pump modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate smooth transition between pump and motor modes**

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between the motor and pump modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Cross-sectional area at ports A and B — Flow area at component inlet and outlet**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

**Report when fluid is not fully liquid — Notification when fluid is not fully liquid**

None (default) | Warning | Error

Whether the block does nothing, generates a warning, or generates an error when the vapor quality is greater than 0, which indicates that the fluid is not fully liquid.

**Check if operating beyond the quadrants of supplied tabulated data — Simulation warning mode for operating conditions outside range of tabulated data**

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the range of tabulated data. If you select **Warning**, the block generates a warning when the fluid pressure gain or the shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the range of tabulated data.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

### Check if operating outside of pump mode — Simulation warning mode for operating conditions outside pump mode

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the pump mode. When you set this parameter to **Warning**, the block generates a warning if the pump transitions to motoring mode. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the pump mode.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Input signal - volumetric and mechanical losses**.

## Version History

Introduced in R2022b

### Extended Capabilities

#### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Compressor (2P) | Positive-Displacement Compressor (2P) | Variable-Displacement Pump (2P)

## Flow Coefficient Parameterized Valve (TL)

Valve with flow area modeled in terms of its  $C_v$  or  $K_v$  flow coefficient

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices



### Description

The Flow Coefficient Parameterized Valve (TL) block models the flow characteristics of a valve using the flow coefficient as a means to relate the flow rate through the ports to the pressure drop across them. The flow coefficient parameterization suits those cases in which the internal geometry of a valve is known in poor detail or in which the flow coefficient is the preferred means of characterizing a valve. The valve model is sufficiently general in its assumptions that it can be applied to a variety of valves; no single valve type is assumed in this block.

### Flow Coefficient Parameterization

The flow coefficient measures the ease with which a fluid driven by a pressure differential flows across a valve. It is an important parameter in the sizing of valves and a convenient way of characterizing one in a model. In this role it is especially useful, as it quantifies in a single number all of the losses incurred in the flow passages of the valve. The flow coefficient is typically measured by the valve manufacturer and reported in a data sheet provided for the valve.

Strictly speaking there are two flow coefficients in common use:  $C_v$  and  $K_v$ . These describe what is fundamentally the same quantity: the volumetric flow rate of water passing through a valve that has been opened to its maximum and set to some standard operating conditions. The flow coefficients differ only in the temperature and pressure drop established during the measurement (the operating conditions) and in the physical units used in its expression:

- $C_v$  is measured at a generally accepted temperature of 60 °F and pressure drop of 1 PSI; it is expressed in imperial units of US gpm. This is the flow coefficient used in the model when the **Flow coefficient specification** block parameter is set to *Cv coefficient (USG/min)* [1 on page 1-893].
- $K_v$  is measured at a generally accepted temperature of 15 °C and pressure drop of 1 bar; it is expressed in metric units of m<sup>3</sup>/h. This is the flow coefficient used in the model when the **Flow coefficient specification** block parameter is set to *Kv coefficient (m<sup>3</sup>/h)*. [2 on page 1-893].

Two values are required of the flow coefficient, a *maximum* and a *minimum*. The maximum corresponds to a valve open to full capacity; this is the value frequently reported in valve data sheets. The minimum corresponds to a valve closed tight, when only leakage flow remains, if any at all. This lower bound imposed on the flow coefficient serves primarily to ensure the numerical robustness of the model. Its exact value is less important than its being a (generally very small) number greater than zero.

### Valve Opening Parameterization

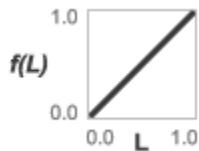
The opening fraction of the valve (the ratio of the valve opening area to its maximum value) is determined during simulation from the input specified at port **L**. This input is the *control signal* and it

is, in some valves, associated with *stroke* or *lift percent*. The control signal can range in value from  $\theta$  to 1. If a lesser or greater value is specified, it is adjusted to the nearest of the two limits. In other words, the signal is *saturated* at  $\theta$  and 1.

The conversion from control signal to opening fraction depends on the **Valve opening characteristics** parameterization selected in the block. The calculation result is the same for all parameterizations when the control signal is either  $\theta$  or 1: a value of  $\theta$  at port **L** always means a maximally (though not necessarily *completely*) closed valve; a value of 1 always means a maximally open valve. At intermediate values, the opening fractions differ:

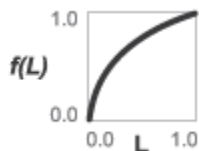
- **Linear** — The valve opening fraction (denoted  $f(L)$  in the figure) is equal to the control signal at port **L**. The two vary in tandem until the control signal either drops below zero (the valve is fully closed) or rises above its maximum value (the valve is fully open). The opening fraction ranges from  $\theta$  to 1 (a statement that does not apply to all valve opening parameterizations).

$$f(L) = L.$$



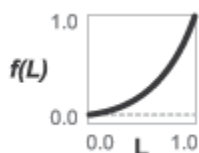
- **Quick opening** — The valve opening fraction,  $f(L)$ , is a power function of the control signal at port **L**. The opening fraction rises quickly with the control signal at values near  $\theta$  and slowly at values near 1. The exponent ( $\alpha$ ) in the calculation determines how the opening rate changes with the control signal. The opening fraction ranges from  $\theta$  to 1.

$$f(L) = L^{1/\alpha}, \quad \alpha > 1.$$



- **Equal percentage** — The valve opening fraction is an exponential function of the control signal at port **L**. The opening fraction rises slowly with the control signal at values near  $\theta$  and quickly at values near 1. The base of the exponent ( $R$ , the *rangeability* of the valve, the ratio between the maximum and minimum flow rates through the ports) determines how the opening rate changes with the control signal. The opening fraction ranges from a small fraction ( $\theta .02$ - $\theta .05$  for typical rangeability values of 20-50) to 1.

$$f(L) = R^{L-1}, \quad R \approx 20 - 50.$$



### Mass Balance

The volume of fluid inside the valve, and therefore the mass of the same, is assumed to be very small and it is, for modeling purposes, ignored. As a result, no amount of fluid can accumulate there. By the principle of conservation of mass, the mass flow rate into the valve through one port must therefore equal that out of the valve through the other port:

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate *into* the valve through the port indicated by the subscript (**A** or **B**).

### Momentum Balance

The causes of those pressure losses incurred in the passages of the valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. It is this cumulative effect that the flow coefficient of the valve enables the block to capture in a model. This constant factors in the momentum balance of the valve *indirectly*, by way of the effective opening area ( $S$ ) of the same:

$$p_A - p_B = \frac{\dot{m}\sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{\rho_{avg}S^2},$$

where:

- $p$  is the pressure at the port indicated by the subscript (**A** or **B**).
- $\rho_{avg}$  is the arithmetic mean of the fluid densities at the ports.
- $\dot{m}$  is the mass flow rate at a port.
- $\dot{m}_{cr}$  is the critical mass flow rate, that at which the flow is assumed to switch between laminar and turbulent regimes:

$$\dot{m}_{cr} = Re_{cr}\mu_{avg}\sqrt{\frac{\pi}{4}S},$$

where  $Re_{cr}$  is the Reynolds number at the transition point and  $\mu_{avg}$  is the average of the dynamic viscosities at the ports.

The effective opening area ( $S$ ) is the product of scaling of the maximum opening area of the valve by the opening fraction ( $f(L)$ ). The calculation imposes a lower bound on the opening area at which only leakage flow remains:

$$S(L) = \begin{cases} S_{max}f(L), & \text{if } S_{max}f(L) > S_{min} \\ S_{min}, & \text{else} \end{cases},$$

where the subscripts **max** and **min** refer to a valve in the fully opened and maximally closed positions; the function  $f(L)$  is the opening fraction calculated from the control signal specified at port **L**:

$$f(L) = \begin{cases} L, & \text{Linear parameterization} \\ L^{1/\alpha}, & \text{Quick opening parameterization} \\ R^L - 1, & \text{Equal percentages parameterization} \end{cases},$$



where  $\alpha$  is obtained from the **Exponent number** block parameter and  $R$  from the **Rangeability** parameter. The maximum opening area is obtained by multiplying the (maximum) flow coefficient by an appropriate conversion factor:

$$S_{\text{Max}} = \begin{cases} \lambda_C C_{v,\text{max}}, & \text{if } C_v \text{ is used} \\ \lambda_K K_{v,\text{max}}, & \text{if } K_v \text{ is used} \end{cases}$$

where:

- $\lambda_C$  is the conversion factor between the maximum flow coefficient in imperial units ( $C_{v,\text{max}}$ ) and the maximum opening area:  $2.4015 \times 10^{-5} \text{ m}^2$ .
- $\lambda_K$  is the conversion factor between the maximum flow coefficient in SI units ( $K_{v,\text{max}}$ ) and the maximum opening area:  $2.7765 \times 10^{-5} \text{ m}^2$ .

The minimum opening area in turn is obtained by multiplying the maximum opening area by the ratio between minimum and maximum flow coefficients:

$$S_{\text{Min}} = \begin{cases} \frac{C_{v,\text{min}}}{C_{v,\text{max}}} S_{\text{max}}, & \text{if } C_v \text{ is used} \\ \frac{K_{v,\text{min}}}{K_{v,\text{max}}} S_{\text{max}}, & \text{if } K_v \text{ is used} \end{cases}$$

## Energy Balance

The valve is modeled as an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. With these assumptions, energy can flow by advection only, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows must then always equal zero:

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is defined as the energy flow rate *into* the valve through one of the ports (**A** or **B**).

## Ports

### Input

#### L – Valve control signal, unitless

physical signal

Port through which to specify the signal that controls the opening of the valve (in certain valve types associated with *stroke* or *lift percent*). The valve is fully closed at a value of 0 and fully open at a value of 1.

### Conserving

#### A – Flow passage

thermal liquid

Opening through which the flow can enter or exit the flow resistance. Which of the ports serves as inlet and which as outlet depends on the direction of flow.

**B – Flow passage**

thermal liquid

Opening through which the flow can enter or exit the flow resistance. Which of the ports serves as inlet and which as outlet depends on the direction of flow.

**Parameters****Flow coefficient specification – Parameterization by which to specify the flow coefficient of the valve**`Cv coefficient (USG/min) (default) | Kv coefficient (m3/h)`

Choice of flow coefficient to specify.  $C_v$  and  $K_v$  differ in the physical conditions of their measurement and in the physical units of their expression. Generally at least one of these is reported in product data sheets provided by the manufacturer. Select the option for which data is available.

 **$C_v$  coefficient at maximum flow – Flow coefficient expressed in imperial units for a maximally open valve**`1 (default) | positive scalar in units of USG/min`

Flow coefficient expressed in imperial units for a valve opened to full capacity. This is the value reported in the valve data sheets when the  $C_v$  coefficient is provided by the manufacturer.

 **$K_v$  coefficient at maximum flow – Flow coefficient expressed in SI units for a maximally open valve**`1 (default) | positive scalar in units of m3/h`

Flow coefficient expressed in SI units for a valve opened to full capacity. This is the value reported in the valve data sheets when the  $K_v$  coefficient is provided by the manufacturer.

 **$C_v$  coefficient at minimum flow – Flow coefficient expressed in imperial units for a maximally closed valve**`1e-4 (default) | positive scalar in units of USG/min`

Flow coefficient expressed in imperial units for a valve that is closed tight and devoid of all flow except for that due to internal leakage between port **A** and port **B**. The primary purpose of this parameter is to ensure the numerical robustness of the model during simulation. Its exact value is less important than its being a very small number greater than zero.

 **$K_v$  coefficient at minimum flow – Flow coefficient expressed in SI units for a maximally closed valve**`1e-4 (default) | positive scalar in units of m3/h`

Flow coefficient expressed in SI units for a valve that is closed tight and devoid of all flow except for that due to internal leakage between port **A** and port **B**. The primary purpose of this parameter is to ensure the numerical robustness of the model during simulation. Its exact value is less important than it being a very small number greater than zero.

**Valve opening characteristics – Parameterization by which to compute the valve opening fraction**`Linear (default) | Quick openingEqual percentages`

Choice of valve opening profile to use during simulation. The selection made here determines how the control signal specified at port **L** is converted into a valve opening fraction (and opening area). See the block description for detail on the opening parameterizations.

**Exponent number — Denominator of the exponent in the quick-opening parameterization**

2 (default) | positive unitless scalar

Number by which to divide the exponent in the governing equation of the quick-opening parameterization. Use a value greater than 1 for a true quick-opening profile, one corresponding to a valve that opens quickly from a maximally closed position but progressively more slowly as it approaches the maximally opened position.

**Valve rangeability — Base of the exponent in the equal-percentages parameterization**

50 (default) | positive unitless scalar

Number to which the exponent is applied in the governing equation of the equal-percentages parameterization. This number is the ratio between the maximum and minimum flow rates through the valve (the first corresponding obtained when the valve is maximally opened and the second when the valve is maximally closed). Typical values range from 20 to 50.

**Cross-sectional area at ports A and B — Flow area at the inlet and outlet of the valve**

0.01 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the flow path at each port. The ports are assumed to be equal in size. The flow area specified here should match those of the inlets of those components to which the valve connects.

**Critical Reynolds number — Reynolds number at which the flow switches between laminar and turbulent**

12 (default) | positive unitless scalar

Reynolds number at which the fluid in the valve is expected to switch between its laminar and turbulent flow regimes. The switch is assumed to occur at once: the transition region that normally exists between the two flow regimes is ignored.

## Version History

Introduced in R2016a

## References

[1] *Control Valve Handbook*. 4th ed. Marshalltown, IA: Fisher Controls International. 2005.

[2] *Flow of Fluids through Valves, Fittings and Pipe*. Stamford, CT: Crane, 2010.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Check Valve (TL) | Poppet Valve (TL) | Gate Valve (TL)

## Flow Divider

Hydraulic two-path flow divider

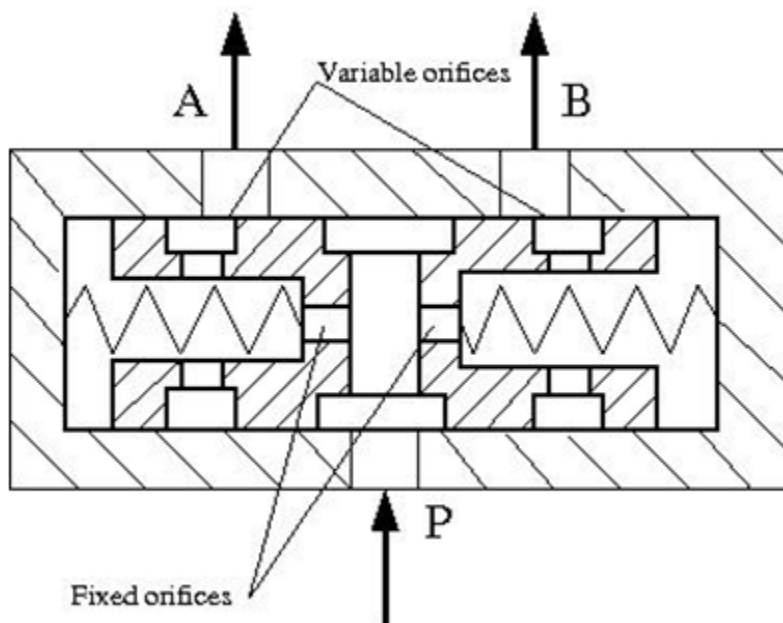


## Library

Flow Control Valves

## Description

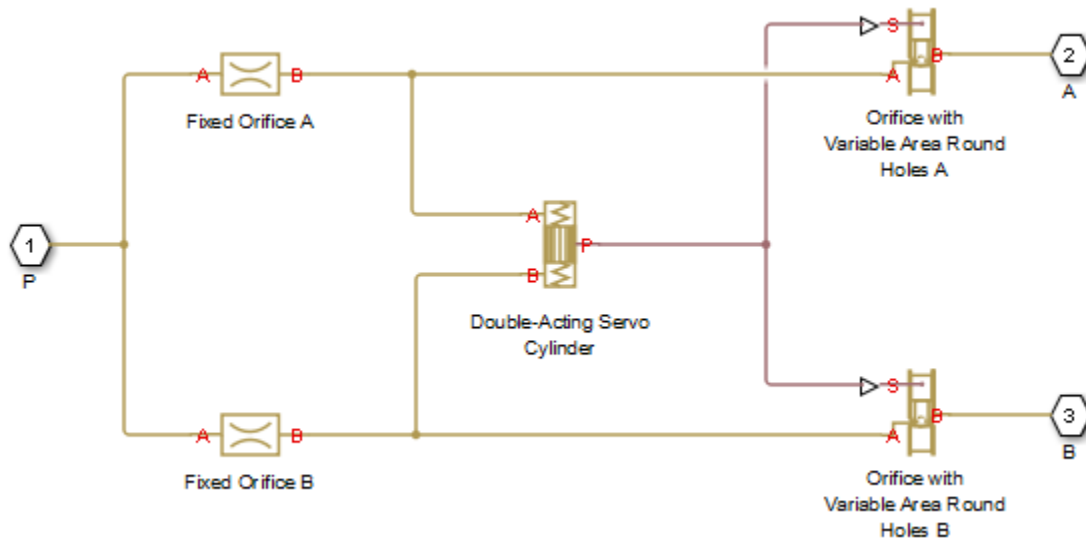
The Flow Divider block simulates a hydraulic two-path flow divider, which consists of a spring-centered spool installed in a case, as shown in the figure.



The flow from the source enters the valve through port P and is split into two parts flowing through the P-A and P-B paths. Each path contains a fixed orifice and a variable orifice. The fixed orifices must be precisely matched to divide flow in equal parts, or arranged in a certain proportion if unequal division is required.

The purpose of variable orifices is to maintain a constant pressure drop across the fixed orifices, regardless of pressure fluctuations at valve outlets. The load increase on any outlet causes the pressure drop across the spool (and across fixed orifices) to change, and thus shift the spool. As a result, the passage areas of variable orifices change until the pressure drop values across the fixed orifices even out.

The model of the flow divider uses the Double-Acting Servo Cylinder, Fixed Orifice, and Orifice with Variable Area Round Holes blocks. The following figure shows the schematic diagram of the model. The Double-Acting Servo Cylinder detects the pressure drop and shifts the variable orifice control member accordingly.



**Note** You cannot use this block as a flow combiner. Use the Flow Divider-Combiner block instead.

## Assumptions and Limitations

- Friction between moving parts is not taken into account.
- Inertia effects are not taken into account.
- Fluid compressibility is not taken into account.
- Leakage flows are assumed to be negligible.
- The hard stops in the Double-Acting Servo Cylinder are assumed to be fully inelastic.

## Parameters

- “Fixed Orifices Tab” on page 1-895
- “Variable Orifices Tab” on page 1-896
- “Servo Cylinder Tab” on page 1-897

### Fixed Orifices Tab

#### Fixed orifice A area

The cross-sectional passage area of the fixed orifice in the P-A path. The default value is  $1e-4 \text{ m}^2$ .

#### Fixed orifice B area

The cross-sectional passage area of the fixed orifice in the P-B path. The default value is  $1e-4 \text{ m}^2$ .

**Fixed orifice A flow discharge coefficient**

Semi-empirical parameter defining the capacity of the fixed orifice in the P-A path. The value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Fixed orifice B flow discharge coefficient**

Semi-empirical parameter defining the capacity of the fixed orifice in the P-B path. The value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Fixed orifice laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Fixed orifice A laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes for the fixed orifice in the P-A path. The default value is 0.999. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Fixed orifice B laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes for the fixed orifice in the P-B path. The default value is 0.999. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Fixed orifice A critical Reynolds number**

The maximum Reynolds number for laminar flow for the fixed orifice in the P-A path. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Reynolds number**.

**Fixed orifice B critical Reynolds number**

The maximum Reynolds number for laminar flow for the fixed orifice in the P-B path. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Reynolds number**.

**Variable Orifices Tab****Diameter of round holes**

Diameter of the round holes in the two identical Variable Orifice with Round Holes blocks. The default value is 0.005 m.

**Number of round holes**

Number of holes in each of the Variable Orifice with Round Holes blocks. The default value is 4.

**Variable orifices flow discharge coefficient**

Semi-empirical parameter defining the orifice capacity of the Variable Orifice with Round Holes blocks. The value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.65.

**Variable orifice A initial opening**

Initial opening of the variable orifice in the P-A path. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or 0 for zero-lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.0025 m.

**Variable orifice B initial opening**

Initial opening of the variable orifice in the P-B path. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or 0 for zero-lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.0025 m.

**Variable orifice laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Variable orifice A laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes for the fixed orifice in the P-A path. The default value is 0.999. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Variable orifice B laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes for the fixed orifice in the P-B path. The default value is 0.999. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Variable orifice A critical Reynolds number**

The maximum Reynolds number for laminar flow through the variable orifice in the P-A path. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Reynolds number**.

**Variable orifice B critical Reynolds number**

The maximum Reynolds number for laminar flow through the variable orifice in the P-B path. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Reynolds number**.

**Variable orifice leakage area**

The total area of possible leaks in each variable orifice when it is completely closed. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from becoming isolated after the orifice is completely closed. The parameter value must be greater than 0. The default value is  $1e-9 \text{ m}^2$ .

**Servo Cylinder Tab****Servo cylinder piston area**

The face area of the piston in the servo cylinder. The default value is  $1.6e-4 \text{ m}^2$ .

**Servo cylinder piston stroke**

The full piston stroke in the servo cylinder, from one hard stop to another. The piston is located initially in the middle of the stroke and can travel half a stroke in the positive and negative direction. The default value is 0.005 m.

**Servo cylinder spring rate**

The spring rate of the centering springs in the servo cylinder. The default value is 1000 N/m.

**Servo cylinder damping coefficient**

The damping coefficient in the contact between the piston and the case of the servo cylinder. The default value is 150 N/(m/s).

**Servo cylinder stop penetration coefficient**

The penetration property of the piston hard stop in the servo cylinder. The hard stop is represented as absolutely inelastic, and its property is characterized by the penetration coefficient. The default value of the coefficient is 1e12 N/m/(m/s).

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

P

Hydraulic conserving port associated with the inlet port P.

A

Hydraulic conserving port associated with the outlet port A.

B

Hydraulic conserving port associated with the outlet port B.

**Version History**

Introduced in R2013a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Double-Acting Servo Cylinder | Fixed Orifice | Flow Divider-Combiner | Orifice with Variable Area Round Holes



**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Flow Divider-Combiner

Hydraulic two-path flow divider-combiner



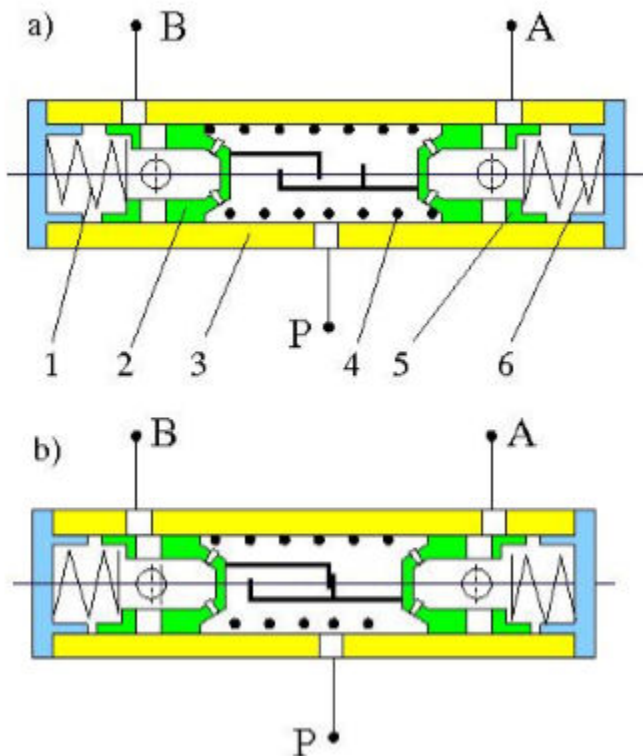
### Library

Flow Control Valves

### Description

The Flow Divider-Combiner block models a hydraulic valve that divides incoming flow through port P (direct flow) between two outlets, and also maintains a specified proportion between return flows through ports A and B in the total flow rate through port P. In other words, the valve works in two distinctive modes: flow divider for direct flow and flow combiner for reverse flow.

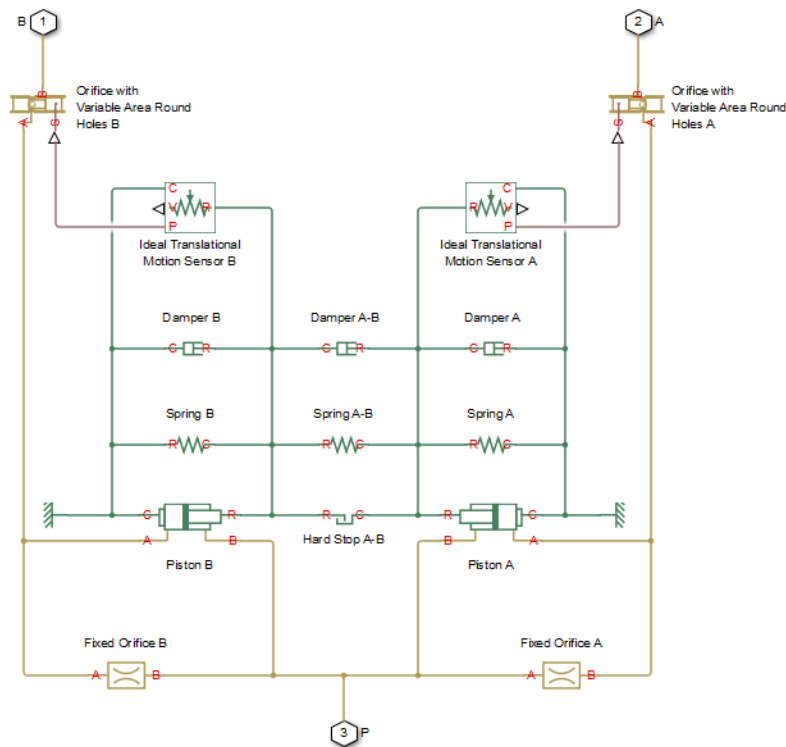
The figure shows a schematic for the flow divider-combiner valve: a) in the divider mode, and b) in the combiner mode.



The valve works as a flow divider when fluid is pumped through port P to ports A and B (schematic figure a). In this mode, fluid passes through fixed orifices in pistons 2 and 5 and through variable orifices formed by round holes in the pistons and case. The pressure differential across pistons moves them apart from each other proportionally to the piston areas and the spring 1 and 6 forces. The spring-suspended pistons and the respective variable orifices work as pressure reducing valves maintaining constant pressure drop across fixed orifices and thus keeping flow rates through them practically constant. The flow divider-combiner valve is essentially a combination of two pressure-compensated flow control valves working in parallel.

For reverse flows (schematic figure b), the pressure differential across pistons forces them against each other until the gap in the hard stop is cleared. The pistons settle at a position where pressure drops across fixed orifices are equal, thus maintaining equal flow rates through branches.

The model of the flow divider-combiner uses the Fixed Orifice, Orifice with Variable Area Round Holes, Double-Acting Hydraulic Cylinder (Simple), Translational Hard Stop, Translational Spring, and Translational Damper blocks, as shown in the block diagram.



The table explains the purpose of each model component.

Name in the block diagram	Purpose (numbers refer to the valve schematic)	Name in the actual component file
Fixed Orifice A	Fixed orifice in piston 5	fixed_orifice_A
Fixed Orifice B	Fixed orifice in piston 2	fixed_orifice_B
Piston A	Piston 5	piston_A
Piston B	Piston 2	piston_B

Name in the block diagram	Purpose (numbers refer to the valve schematic)	Name in the actual component file
Hard Stop A-B	Hard stop between pistons 2 and 5	hard_stop_A_B
Spring A	Spring 6	spring_A
Spring A-B	Spring 4	spring_A_B
Spring B	Spring 1	spring_B
Damper A	Spring 6 damping	damper_A
Damper A-B	Spring 4 damping	damper_A_B
Damper B	Spring 1 damping	damper_B
Orifice with Variable Area Round Holes A	Variable orifice created by round holes in piston 5 and the case	variable_orifice_A
Orifice with Variable Area Round Holes B	Variable orifice created by round holes in piston 2 and the case	variable_orifice_B
Ideal Translational Motion Sensor A	Measures piston 5 displacement and exports the measurement to the Orifice with Variable Area Round Holes A	sensor_A
Ideal Translational Motion Sensor B	Measures piston 2 displacement and exports the measurement to the Orifice with Variable Area Round Holes B	sensor_B

The block orientations in the model are explained by the structure section of the underlying component file, reproduced below:

```
connections
  connect(P, fixed_orifice_A.A, fixed_orifice_B.A, piston_A.B, piston_B.B);
  connect(fixed_orifice_A.B, piston_A.A, variable_orifice_A.A);
  connect(fixed_orifice_B.B, piston_B.A, variable_orifice_B.A);
  connect(B, variable_orifice_B.B);
  connect(A, variable_orifice_A.B);
  connect(reference.V, piston_A.C, spring_A.C, damper_A.C, sensor_A.C, ...
    piston_B.C, spring_B.C, damper_B.C, sensor_B.C);
  connect(piston_A.R, spring_A.R, hard_stop_A_B.C, spring_A_B.C, ...
    damper_A.R, damper_A_B.R, sensor_A.R);
  connect(piston_B.R, spring_B.R, hard_stop_A_B.R, spring_A_B.R, ...
    damper_B.R, damper_A_B.C, sensor_B.R);
  connect(sensor_A.P, variable_orifice_A.S);
  connect(sensor_B.P, variable_orifice_B.S);
end
```

## Assumptions and Limitations

The block does not account for inertia, friction, and hydraulic forces. For additional assumptions and limitations, see the reference pages of the underlying member blocks.

## Parameters

- “Fixed Orifices Tab” on page 1-903
- “Pistons Tab” on page 1-903
- “Springs/Dampers Tab” on page 1-904
- “Variable Orifices Tab” on page 1-904
- “Hard Stop Between Pistons Tab” on page 1-906

### Fixed Orifices Tab

#### Fixed orifice A area

The cross-sectional passage area of the fixed orifice in piston 5 (the P-A path). The default value is  $1.5e-5 \text{ m}^2$ .

#### Fixed orifice B area

The cross-sectional passage area of the fixed orifice in piston 2 (the P-B path). The default value is  $1.5e-5 \text{ m}^2$ .

#### Fixed orifice flow discharge coefficient

Semi-empirical coefficient for fixed orifice capacity characterization. The value depends on the orifice geometrical properties, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

#### Fixed orifice laminar transition specification

Select how the block transitions between the laminar and turbulent regimes for the fixed orifices:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Fixed orifice laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Fixed orifice critical Reynolds number** parameter.

#### Fixed orifice laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Pressure ratio**.

#### Fixed orifice critical Reynolds number

The maximum Reynolds number for laminar flow in the fixed orifices. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Fixed orifice laminar transition specification** parameter is set to **Reynolds number**.

### Pistons Tab

#### Piston A area

The face area of Piston A (piston 5). The default value is  $2e-4 \text{ m}^2$ .

#### Piston A stroke

The full stroke of Piston A. The default value is 5 mm.

**Piston A initial extension**

The initial extension of Piston A. The default value is 0 m.

**Piston B area**

The face area of Piston B (piston 2). The default value is  $2e-4 \text{ m}^2$ .

**Piston B stroke**

The full stroke of Piston B. The default value is 5 mm.

**Piston B initial extension**

The initial extension of Piston B. The default value is 0 m.

**Piston stop penetration coefficient**

The penetration property of colliding bodies in the underlying cylinder blocks, which is assumed to be absolutely plastic. The default value is  $1e12 \text{ s}^2/\text{N/m}^2$ .

**Springs/Dampers Tab****Spring A rate**

Spring rate of Spring A (spring 6). The default value is  $1e3 \text{ N/m}$ .

**Spring A preload**

This parameter sets the initial high-priority target value for the **Deformation** variable in the underlying Spring A block. For more information, see “Variable Priority for Model Initialization”. The default value is 0.1 m.

**Damping coefficient A**

Damping coefficient of Damper A (spring 6 damping). The default value is  $150 \text{ N/(m/s)}$ .

**Spring B rate**

Spring rate of Spring B (spring 1). The default value is  $1e3 \text{ N/m}$ .

**Spring B preload**

This parameter sets the initial high-priority target value for the **Deformation** variable in the underlying Spring B block. For more information, see “Variable Priority for Model Initialization”. The default value is -0.1 m.

**Damping coefficient B**

Damping coefficient of Damper B (spring 1 damping). The default value is  $150 \text{ N/(m/s)}$ .

**Spring A-B rate**

Spring rate of Spring A-B (spring 4). The default value is  $1e3 \text{ N/m}$ .

**Spring A-B preload**

This parameter sets the initial high-priority target value for the **Deformation** variable in the underlying Spring A-B block. For more information, see “Variable Priority for Model Initialization”. The default value is 0.1 m.

**Damping coefficient A\_B**

Damping coefficient of Damper A-B (spring 4 damping). The default value is  $150 \text{ N/(m/s)}$ .

**Variable Orifices Tab****Variable orifice A hole diameter**

Diameter of the holes in the underlying Orifice with Variable Area Round Holes A block. The default value is 0.0025 m.

**Variable orifice B hole diameter**

Diameter of the holes in the underlying Orifice with Variable Area Round Holes B block. The default value is 0.0025 m.

**Number of hole pairs in the variable orifice**

Number of holes in each of the Orifice with Variable Area Round Holes blocks. The default value is 4.

**Variable orifice flow discharge coefficient**

Semi-empirical parameter defining the orifice capacity of the Orifice with Variable Area Round Holes blocks. The value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Variable orifice A initial center distance**

Initial opening in the underlying Orifice with Variable Area Round Holes A block. The parameter value can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The default value is 0.0025 m, which corresponds to the position of piston 5 in the valve schematic drawing.

**Variable orifice B initial center distance**

Initial opening in the underlying Orifice with Variable Area Round Holes B block. The parameter value can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The default value is -0.0025 m, which corresponds to the position of piston 2 in the valve schematic drawing.

**Variable orifice laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes for the variable orifices:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Variable orifice laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Variable orifice critical Reynolds number** parameter.

**Variable orifice laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Variable orifice critical Reynolds number**

The maximum Reynolds number for laminar flow through the variable orifices. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The default value is 10. This parameter is visible only if the **Variable orifice laminar transition specification** parameter is set to **Reynolds number**.

**Variable orifice leakage area**

The total area of possible leaks in each variable orifice when it is completely closed. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from becoming isolated after the orifice is completely closed. The parameter value must be greater than 0. The default value is  $1e-9 \text{ m}^2$ .

## Hard Stop Between Pistons Tab

### Hard stop upper bound

Gap between the slider and the upper bound in the underlying Hard Stop block. The default value is 5.1 mm.

### Hard stop lower bound

Gap between the slider and the lower bound in the underlying Hard Stop block. The default value is 1 mm.

### Hard stop stiffness

The elastic property of colliding bodies in the hard stop. The default value is 1e8 N/m.

### Hard stop damping coefficient

The dissipating property of colliding bodies in the hard stop. The default value is 150 N/(m/s).

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

P

Hydraulic conserving port associated with the inlet port P.

A

Hydraulic conserving port associated with the outlet port A.

B

Hydraulic conserving port associated with the outlet port B.

## Version History

Introduced in R2014b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Double-Acting Hydraulic Cylinder (Simple) | Fixed Orifice | Flow Divider | Orifice with Variable Area Round Holes | Translational Damper | Translational Hard Stop | Translational Spring



**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Gas-Charged Accumulator (IL)

Gas-charged accumulator in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Tanks & Accumulators

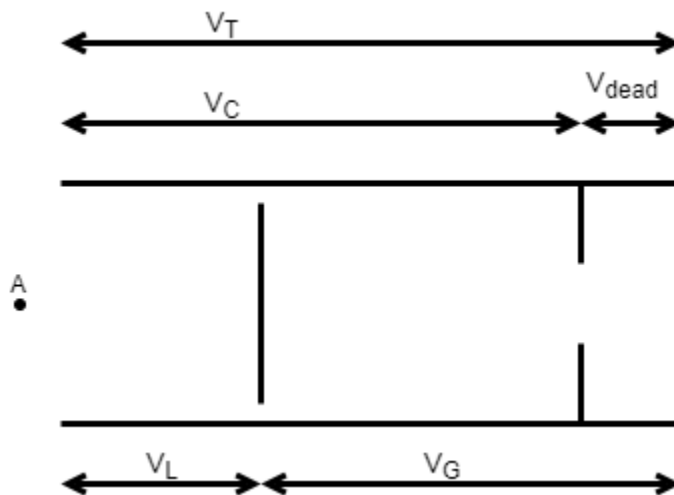


### Description

The Gas-Charged Accumulator (IL) block represents a gas-charged accumulator in an isothermal liquid network. The accumulator consists of a precharged gas chamber and a liquid chamber. The chambers are separated by a bladder, a piston, or any kind of a diaphragm.

As the liquid pressure at the accumulator inlet becomes greater than the precharge pressure, liquid enters the accumulator and compresses the gas through a polytropic process. A decrease in the liquid pressure causes the gas to decompress and discharge stored liquid into the system. The separator motion is restricted by a hard stop when the liquid volume is zero and when the liquid volume is at the liquid chamber capacity. The liquid chamber capacity is the total accumulator volume minus the minimum gas volume.

Inlet liquid resistance, and separator properties such as inertia and damping are not modeled. The flow rate is positive if liquid flows into the accumulator.



This diagram represents a gas-charged accumulator. The total accumulator volume,  $V_T$ , is divided into the liquid chamber on the left and the gas chamber on the right by the vertical separator. The distance between the left side and the separator defines the liquid volume,  $V_L$ . The distance between the right side and the separator defines the gas volume,  $V_G$ . The liquid chamber capacity,  $V_C$ , is less than the total accumulator volume, so that the gas volume never becomes zero:

$$V_L = V_T - V_G$$

$$V_C = V_T - V_{dead}$$

where:

- $V_T$  is the total volume of the accumulator, including the liquid chamber and the gas chamber.
- $V_L$  is the volume of the liquid in the accumulator.
- $V_G$  is the volume of the gas in the accumulator.
- $V_C$  is the liquid chamber capacity ( $V_T - V_G$ ).
- $V_{dead}$  is the gas chamber dead volume, a small portion of the gas chamber that remains filled with gas when the liquid chamber is at capacity.

The hard stop contact pressure is modeled with a stiffness term and a damping term. The relationship of the gas pressure and gas volume between the current state and the precharge state is polytropic and pressure is balanced at the separator:

$$p_G V_G^{k_{sh}} = p_{pr} V_T^{k_{sh}},$$

where:

- $p_G$  is the gas pressure in the gas chamber.
- $p_{pr}$  is the pressure in the gas chamber when the liquid chamber is empty
- $k_{sh}$  is the specific heat ratio (adiabatic index).

### Conservation of Mass

Conservation of mass is represented by the following equation.

$$\left\{ \begin{array}{ll} \dot{p}_I \frac{d\rho_I}{dp_I} V_L + \rho_I \dot{V}_L = \dot{m}_A, & \text{compressibility on} \\ \rho_I \dot{V}_L = \dot{m}_A, & \text{compressibility of f} \end{array} \right.$$

where:

- $p_I$  is the liquid pressure in the liquid chamber, which is equal to the pressure at the accumulator inlet.
- $\dot{m}_A$  is the mass flow rate of liquid coming into port **A**.
- $\rho_I$  is the density of the liquid in the liquid chamber.

$$\dot{V}_L = \begin{cases} \frac{\dot{p}_I}{k_{sh} \frac{p_G}{V_G}}, & \text{if } 0 < V_L < V_C \\ \frac{\dot{p}_I}{k_{sh} \frac{p_G}{V_G} + K_{stiff}}, & \text{else} \end{cases}$$

where  $K_{stiff}$  is the hard-stop stiffness coefficient.

### Conservation of Momentum

Conservation of momentum is represented by:

$$p_I = p_G + p_{HS}$$

where  $p_{HS}$  is the hard-stop contact pressure.

$$p_{HS} = \begin{cases} (V_L - V_C)K_{stiff}, & \text{if } V_L \geq V_C \\ V_L K_{stiff}, & \text{if } V_L \leq 0 \\ 0, & \text{else} \end{cases}$$

## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Isothermal liquid port associated with the accumulator inlet. The flow rate is positive if liquid flows into the accumulator.

## Parameters

### Total accumulator volume – Accumulator volume

8e-3 m<sup>3</sup> (default) | positive scalar

Total volume of the accumulator, including the liquid chamber and the gas chamber. It is the sum of the liquid chamber capacity and the minimum gas volume.

### Minimum gas volume – Gas chamber dead volume

4e-5 m<sup>3</sup> (default) | positive scalar

Gas chamber dead volume, which is defined as a small portion of the gas chamber that remains filled with gas when the liquid chamber is filled to capacity. The block requires a nonzero value to avoid divide-by-zero when the liquid chamber is at capacity.

### Precharge pressure – Gas chamber pressure

1.101325 MPa (default) | positive scalar

Pressure in the gas chamber when the liquid chamber is empty.

### Specific heat ratio – Specific heat ratio

1.4 (default) | positive scalar

Specific heat ratio (adiabatic index). To account for heat exchange, set it to a value normally between 1 and 2, depending on the properties of the gas in the gas chamber. For dry air at 20°C, this value is 1 for an isothermal process or 1.4 for an adiabatic (and isentropic) process.

**Hard stop stiffness coefficient – Proportionality constant**1e4 MPa/m<sup>3</sup> (default) | positive scalar

Proportionality constant of the hard-stop contact pressure with respect to the liquid volume penetrated into the hard stop. The hard stops are used to restrict the liquid volume between zero and liquid chamber capacity.

**Fluid dynamic compressibility – Fluid compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

**Version History**

Introduced in R2020a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Spring-Loaded Accumulator (IL)

# Gas-Charged Accumulator

Hydraulic accumulator with gas as compressible medium

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Accumulators



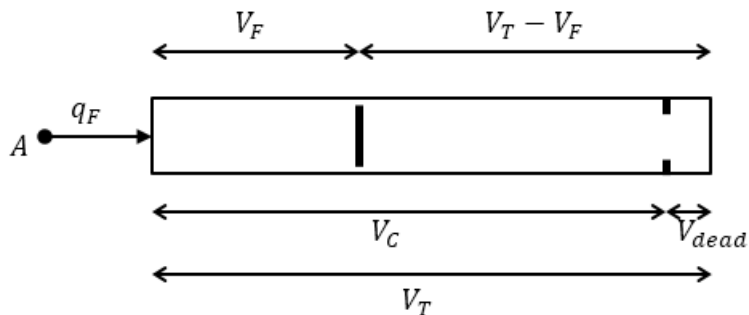
## Description

The Gas-Charged Accumulator block models a gas-charged accumulator that consists of a precharged gas chamber and a fluid chamber. The fluid chamber is connected to a hydraulic system. The chambers are separated by a bladder, a piston, or any kind of a diaphragm.

As the fluid pressure at the accumulator inlet becomes greater than the precharge pressure, fluid enters the accumulator and compresses the gas, storing hydraulic energy. A decrease in the fluid pressure causes the gas to decompress and discharge the stored fluid into the system.

During typical operations, the pressure in the gas chamber is equal to the pressure in the fluid chamber. However, if the pressure at the accumulator inlet drops below the precharge pressure, the gas chamber becomes isolated from the system. In this situation, the fluid chamber is empty and the pressure in the gas chamber remains constant and equal to the precharge pressure. The pressure at the accumulator inlet depends on the hydraulic system to which the accumulator is connected. If the pressure at the accumulator inlet builds up to the precharge pressure or higher, fluid enters the accumulator again.

The motion of the separator between the fluid chamber and the gas chamber is restricted by two hard stops that limit the expansion and contraction of the fluid volume. The fluid volume is limited when the fluid chamber is at capacity and when the fluid chamber is empty. The hard stops are modeled with finite stiffness and damping. This means that it is possible for the fluid volume to become negative or greater than the fluid chamber capacity, depending on the values of the hard-stop stiffness coefficient and the accumulator inlet pressure.



The diagram represents a gas-charged accumulator. The vertical separator divides the total accumulator volume,  $V_T$ , into the fluid chamber on the left and the gas chamber on the right. The distance between the left side and the separator defines the fluid volume,  $V_F$ . The distance between

the right side and the separator defines the gas volume,  $V_T - V_F$ . The fluid chamber capacity,  $V_C$ , is less than the total accumulator volume,  $V_T$ , so that the gas volume never becomes zero.

The block models the hard stop contact pressure with a stiffness term and a damping term. The relationship of the gas pressure and gas volume between the current state and the precharge state is given by the polytropic relation, with pressure balanced at the separator

$$(p_G + p_A)(V_T - V_F)^k = (p_{pr} + p_A)V_T^k$$

$$p_F = p_G + p_{HS}$$

$$V_C = V_T - V_{dead}$$

$$p_{HS} = \begin{cases} K_S(V_F - V_C) + K_d q_F^\dagger (V_F - V_C) & \text{if } V_F \geq V_C \\ K_S V_F - K_d q_F^- V_F & \text{if } V_F \leq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$q_F^\dagger = \begin{cases} q_F & \text{if } q_F \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$q_F^- = \begin{cases} q_F & \text{if } q_F \leq 0 \\ 0 & \text{otherwise} \end{cases}$$

where:

$V_T$	Total volume of the accumulator, including the fluid chamber and the gas chamber
$V_F$	Volume of fluid in the accumulator
$V_{init}$	Initial volume of fluid in the accumulator
$V_C$	Fluid chamber capacity, which is the difference between total accumulator volume and the gas chamber dead volume
$V_{dead}$	Gas chamber dead volume, which is a small portion of the gas chamber that remains filled with gas when the fluid chamber is at capacity
$p_F$	Fluid pressure (gauge) in the fluid chamber, which is equal to the pressure at the accumulator inlet
$p_{pr}$	Pressure (gauge) in the gas chamber when the fluid chamber is empty
$p_A$	Atmospheric pressure
$p_G$	Gas pressure (gauge) in the gas chamber
$p_{HS}$	Hard-stop contact pressure
$K_S$	Hard-stop stiffness coefficient
$K_d$	Hard-stop damping coefficient
$k$	Specific heat ratio (adiabatic index)
$q_F$	Fluid flow rate into the accumulator, which is positive if fluid flows into the accumulator

The flow rate into the accumulator is the rate of change of the fluid volume:

$$q_F = \frac{dV_F}{dt}.$$

At  $t = 0$ , the initial condition is  $V_F = V_{\text{init}}$ , where  $V_{\text{init}}$  is the value you assign to the **Initial fluid volume** parameter.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- The process in the gas chamber is assumed to be polytropic.
- Loading on the separator, such as inertia or friction, is not considered.
- Inlet hydraulic resistance is not considered.
- Fluid compressibility is not considered.

### Ports

#### Conserving

##### A — Accumulator inlet

hydraulic

Hydraulic conserving port associated with the accumulator inlet. The flow rate is positive if fluid flows into the accumulator.

### Parameters

#### Total accumulator volume — Accumulator volume, including fluid chamber and gas chamber

8e-3 m<sup>3</sup> (default) | positive scalar

Total volume of the accumulator, including the fluid chamber and the gas chamber. This value is the sum of the fluid chamber capacity and the minimum gas volume.

#### Minimum gas volume — Gas chamber dead volume

4e-5 m<sup>3</sup> (default) | positive scalar

Gas chamber dead volume, a small portion of the gas chamber that remains filled with gas when the fluid chamber is at capacity. A nonzero volume is necessary so that the gas pressure does not become infinite when the fluid chamber is at capacity.

#### Precharge pressure (gauge) — Pressure in gas chamber when fluid chamber is empty

10e5 Pa (default) | positive scalar

Pressure (gauge) in the gas chamber when the fluid chamber is empty.



**Specific heat ratio – Adiabatic index**

1.4 (default) | scalar, typically between 1 and 2

Specific heat ratio, also known as the adiabatic index. To account for heat exchange, set this parameter to a value, typically between 1 and 2, depending on the properties of the gas in the gas chamber. For dry air at 20°C, this value is 1 for an isothermal process and 1.4 for an adiabatic and isentropic process.

**Hard-stop stiffness coefficient – Proportionality constant for hard-stop stiffness**1e10 Pa/m<sup>3</sup> (default) | nonnegative scalar

Proportionality constant of the hard-stop contact pressure with respect to the fluid volume penetrated into the hard stop. The block uses the hard stops to restrict the fluid volume between zero and fluid chamber capacity.

**Hard-stop damping coefficient – Proportionality constant for hard-stop damping**1e10 Pa\*s/m<sup>6</sup> (default) | nonnegative scalar

Proportionality constant of the hard-stop contact pressure with respect to the flow rate and the fluid volume penetrated into the hard stop. The block uses the hard stops to restrict the fluid volume between zero and fluid chamber capacity.

## Version History

Introduced in R2006a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Spring-Loaded Accumulator

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Gas-Charged Accumulator (TL)

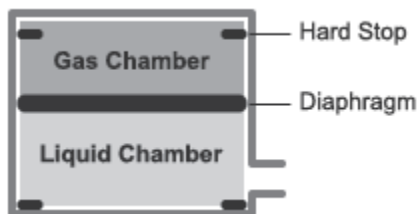
Gas-charged accumulator in a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Tanks & Accumulators



### Description

The Gas-Charged Accumulator (TL) block represents a pressurized thermal liquid container with a compressed gas charge. The accumulator consists of thermal liquid and gas chambers separated by a hermetic and insulated diaphragm.



### Accumulator Schematic

If the inlet pressure is greater than the gas charge pressure, the liquid chamber volume increases, compressing the gas chamber. If the inlet pressure is lower than the gas charge pressure, the liquid chamber volume decreases, decompressing the gas chamber.

Hard stops limit the diaphragm motion when the liquid chamber is at capacity and when the liquid chamber is empty. If the specified spring stiffness is too low, the liquid volume can momentarily fall below zero or rise above capacity. Use the **Hard stop stiffness coefficient** parameter to correct this.

### Mass Balance

The mass conservation equation in the liquid chamber is

$$V_L \rho_L \left( \frac{1}{\beta_L} \frac{dp_L}{dt} - \alpha_L \frac{dT_L}{dt} \right) + \rho_L \frac{dV_L}{dt} = \dot{m}_A,$$

where:

- $\rho_L$  is the thermal liquid density.
- $\beta_L$  is the isothermal bulk modulus.
- $\alpha_L$  is the isobaric thermal expansion coefficient.
- $p_L$  is the thermal liquid pressure.
- $T_L$  is the thermal liquid temperature.
- $\dot{m}_A$  is the thermal liquid mass flow rate into the accumulator through port **A**.

The block computes the time variation of the liquid chamber volume using the conditional equation

$$\frac{dV_L}{dt} = \begin{cases} \frac{\dot{p}_L}{kp_{pr}V_T^k V_G^{(-k-1)} + K_s + K_d \dot{m}^+ / \rho_L}, & V_L \geq V_C \\ \frac{\dot{p}_L}{kp_{pr}V_T^k V_G^{(-k-1)} + K_s - K_d \dot{m}^- / \rho_L}, & V_L \leq 0 \\ \frac{\dot{p}_L}{kp_{pr}V_T^k V_G^{(-k-1)}}, & \text{Else} \end{cases}$$

where:

- $K_s$  is the **Hard-stop stiffness coefficient** parameter.
- $K_d$  is the **Hard-stop damping coefficient** parameter.
- $\dot{m}^+$  is the mass flow rate into the liquid chamber when the accumulator diaphragm contacts the top hard stop:

$$\dot{m}^+ = \begin{cases} \dot{m}, & \dot{m} > 0 \\ 0, & \text{Else} \end{cases}$$

- $\dot{m}^-$  is the mass flow rate from the liquid chamber when the accumulator diaphragm contacts the bottom hard stop:

$$\dot{m}^- = \begin{cases} \dot{m}, & \dot{m} < 0 \\ 0, & \text{Else} \end{cases}$$

### Momentum Balance

The momentum conservation equation in the accumulator volume is

$$p_L = p_G + p_{HS},$$

where  $p_{HS}$  is the hard-stop contact pressure:

- $$p_{HS} = \begin{cases} (V_L - V_C)(K_s + K_d \dot{m}^+ / \rho), & V_L \geq V_C \\ V_L(K_s - K_d \dot{m}^- / \rho), & V_L \leq 0 \\ 0, & \text{Else} \end{cases}$$

### Energy Balance

The energy conservation equation in the liquid chamber volume is

$$\frac{d}{dt}(\rho_L u_L V_L) = \phi_A + \phi_H,$$

where:

- $u_L$  is the thermal liquid specific internal energy.
- $\phi_A$  is the energy flow rate into the liquid chamber through the accumulator inlet.
- $\phi_H$  is the thermal energy flow rate into the liquid chamber through the accumulator wall.

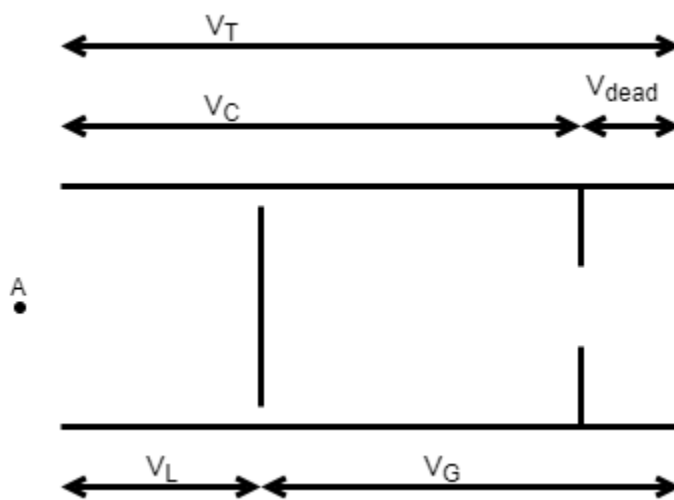
### Chamber Volumes

The liquid chamber volume is the difference between the total accumulator volume and the gas chamber volume:

$$V_L = V_T - V_G,$$

where:

- $V_L$  is the liquid chamber volume.
- $V_T$  is the total accumulator volume.
- $V_G$  is the gas chamber volume.



### Chamber Volumes

The liquid chamber capacity is the difference between the total accumulator volume and the dead volume of gas in the accumulator at full capacity:

$$V_C = V_T - V_{Dead},$$

where:

- $V_C$  is the liquid chamber capacity.
- $V_{Dead}$  is the dead volume of gas at full capacity.

The gas chamber pressure and volume follow from the precharge states as described by the polytropic equation

$$p_G V_G^k = p_{pr} V_T^k,$$

where:

- $p_G$  is the gas chamber pressure at a given time step.
- $V_G$  is the gas chamber volume at a given time step.
- $p_{pr}$  is the precharge gas chamber pressure when the liquid chamber is empty.

- $V_T$  is the total liquid chamber volume.
- $k$  is the polytropic index.

### Initial Targets

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- The block treats the gas chamber compression as a polytropic process.
- The block ignores diaphragm loading.
- The block ignores the effects of fluid inertia.

### Ports

#### Conserving

##### A — Liquid port

thermal liquid

Thermal liquid conserving port associated with the accumulator inlet. The flow rate is positive if liquid flows into the accumulator.

##### H — Heat port

thermal

Thermal conserving port associated with the thermal mass of the liquid volume.

### Parameters

#### Total accumulator volume — Accumulator volume

$8e-3 \text{ m}^3$  (default) | positive scalar

Total volume of the accumulator, including the liquid chamber and the gas chamber. This is the sum of the liquid chamber capacity and the minimum gas volume.

#### Minimum gas volume — Gas chamber dead volume

$4e-5 \text{ m}^3$  (default) | positive scalar

Gas chamber dead volume. This is the amount of remaining gas when the liquid chamber is full. A nonzero volume is necessary so that the gas pressure does not become infinite when the liquid chamber is full.

#### Precharge pressure (gauge) — Gas chamber pressure

0 MPa (default) | nonnegative scalar

Initial gauge pressure of the empty accumulator chamber. Fluid enters the accumulator if the inlet pressure is equal to or greater than the precharge pressure.

**Specific heat ratio — Specific heat ratio**

1.4 (default) | positive scalar

Specific heat ratio for the gas in the chamber. This value is typically 1.4 for air at 20°C.

**Cross-sectional area at port A — Inlet cross-sectional area**

0.01 m<sup>2</sup> positive scalar (default)

Flow cross-sectional area at the accumulator inlet.

**Hard stop stiffness coefficient — Stiffness coefficient**

1e4 MPa/m<sup>3</sup> (default) | positive scalar

Stiffness coefficient of the top and bottom accumulator hard stops. The hard stops restrict diaphragm motion between zero and the maximum liquid chamber level.

**Hard-stop damping coefficient — Damping coefficient**

1e4 MPa\*s/m<sup>6</sup> (default) | positive scalar

Damping coefficients of the top and bottom accumulator hard stops. The hard stops restrict diaphragm motion between zero and the maximum liquid chamber level. The damping coefficients account for the dissipative portion of the hard-stop contact forces.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Tank (TL)

# Gate Valve

Hydraulic gate valve

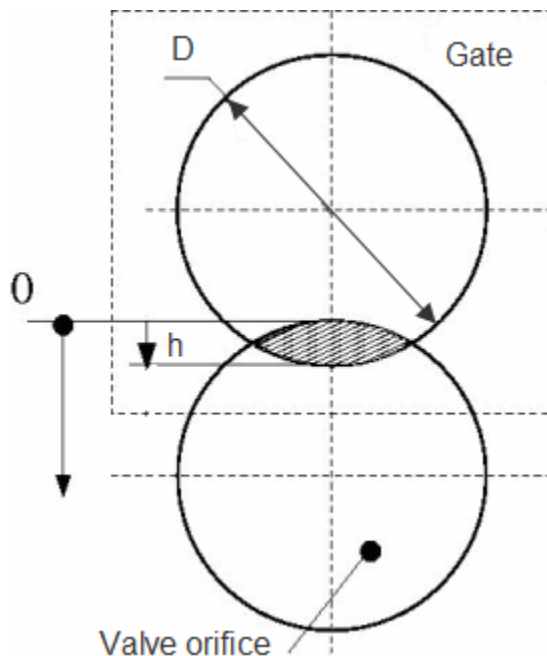


## Library

Flow Control Valves

## Description

The Gate Valve block models a valve consisting of a round orifice in the valve housing and a flat gate, which moves perpendicular to the orifice axis. The orifice in the gate has the same diameter as the orifice in the housing. As the gate moves, it opens or closes the valve passage (shown as a shaded area in the following illustration).



The flow rate through the valve is proportional to the valve opening and to the pressure differential across the valve. The flow rate is determined according to the following equations:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

$$\Delta p = p_A - p_B,$$

$$h = x_0 + x$$

$$A(h) = \begin{cases} A_{leak} & \text{for } h \leq 0 \text{ or } h > 2D \\ D^2 \cdot \left( \frac{\alpha}{2} - \frac{\sin(2\alpha)}{4} \right), \alpha = a \cos \left| 1 - \frac{h}{D} \right| & \text{for } 0 < h \leq 2D \end{cases}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A(h)$	Instantaneous orifice passage area
$x_0$	Initial opening
$x$	Gate displacement from initial position
$h$	Valve opening
$D$	Orifice diameter
$\rho$	Fluid density
$A_{leak}$	Closed valve leakage area
$p_{cr}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{cr}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = (p_{avg} + p_{atm})(1 - B_{lam})$$

$$p_{avg} = (p_A + p_B)/2$$

where

$p_{avg}$	Average pressure between the block terminals
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where



$D_H$	Valve instantaneous hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

Connections A and B are hydraulic conserving ports. Connection S is a physical signal port that controls the gate displacement. The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S opens the valve.

## Basic Assumptions and Limitations

- No inertial effects are taken into account.

## Parameters

### Valve orifice diameter

The diameter of the valve orifice. The orifices in the valve housing and in the gate have the same diameter. The default value is 0.01 m.

### Initial opening

The initial opening of the valve. The parameter can take both positive and negative values. The default value is 0.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.65.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 10. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system

from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

S

Physical signal port that controls the gate displacement. The signal applied to this port is treated as translational motion, in meters.

## Version History

**Introduced in R2011b**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Ball Valve | Needle Valve | Poppet Valve | Pressure-Compensated Flow Control Valve

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Gate Valve (IL)

Gate valve in an isothermal liquid system

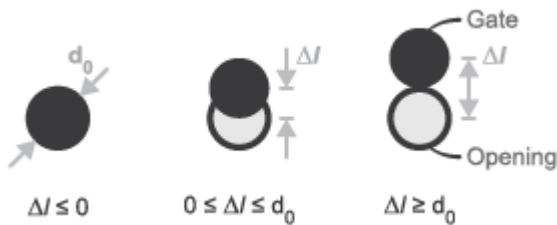
**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



### Description

The Gate Valve (IL) block represents flow control by a gate valve in an isothermal liquid network. The valve comprises a round, sharp-edged orifice and a round gate with the same diameter. The gate opens or closes according to the displacement signal at port **S**. A positive signal retracts the gate and opens the valve.

### Opening Area



### Gate Valve Opening Schematic

The area open to flow as the gate retracts is:

$$A_{open} = \frac{\pi d_0^2}{4} - A_{shielded},$$

where  $d_0$  is the **Valve orifice diameter**. The area shielded by the gate in a partially open valve is:

$$A_{shielded} = \frac{d_0^2}{2} \cos^{-1}\left(\frac{\Delta l}{d_0}\right) - \frac{\Delta l}{2} \sqrt{d_0^2 - (\Delta l)^2},$$

where  $\Delta l$  is the gate displacement, which is the sum of the signal at port **S** and the **Gate position when fully covering orifice**.

If displacement exceeds the **Orifice diameter**, the valve area  $A_{open}$  is the sum of the maximum orifice area and the **Leakage area**:

$$A_{open} = \frac{\pi}{4} d_0^2 + A_{leak}.$$

For any combination of the signal at port **S** and the gate offset that is less than 0, the minimum valve area is the **Leakage area**.

## Numerically Smoothed Displacement

When the valve is in a near-open or near-closed position, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the gate displacement between  $\theta$  and the **Valve orifice diameter** parameter. For more information, see “Numerical Smoothing”.

## Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{\text{valve}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2\right) [\Delta p^2 + \Delta p_{\text{crit}}^2]^{1/4}}} \Delta p$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{\text{valve}}$  is the valve open area.
- $A_{\text{port}}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{\text{crit}}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{\text{crit}}$ , which is the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{\text{crit}} = \frac{\pi \bar{\rho}}{8 A_{\text{valve}}} \left( \frac{\nu Re_{\text{crit}}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{\text{loss}}$  is calculated as:

$$PR_{\text{loss}} = \frac{\sqrt{1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{\text{valve}}}{A_{\text{port}}}}{\sqrt{1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{\text{valve}}}{A_{\text{port}}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{\text{loss}}$  is 1.

## Ports

### Input

#### S — Gate displacement, m

physical signal

Physical signal port associated with the valve gate displacement, in m. A positive signal retracts the gate and opens the valve.

### Conserving

#### **A — Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with valve inlet A.

#### **B — Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with valve inlet B.

### Parameters

#### **Valve orifice diameter — Orifice diameter**

$5e-3 \text{ m}^2$  (default) | positive scalar

Valve open-area diameter.

#### **Gate position when fully covering orifice — Gate offset**

$0 \text{ m}$  (default) | positive scalar

Gate offset when the valve is closed. A positive, nonzero value indicates a partially open valve when the signal at port **S** is 0. A negative, nonzero value indicates an overlapped valve that remains closed for an initial positive displacement set by the physical signal at port **S**.

#### **Leakage area — Gap area when in fully closed position**

$1e-10 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

#### **Cross-sectional area at ports A and B — Orifice area at conserving ports**

$\text{inf} \text{ m}^2$  (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

#### **Discharge coefficient — Discharge coefficient**

$0.64$  (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows.

#### **Critical Reynolds number — Upper Reynolds number limit for laminar flow**

$150$  (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

#### **Smoothing factor — Numerical smoothing factor**

$0.01$  (default) | positive scalar in the range  $[0,1]$

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions.

**Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Needle Valve (IL) | Poppet Valve (IL) | Orifice (IL)

## Gate Valve (G)

Gate valve in a gas network

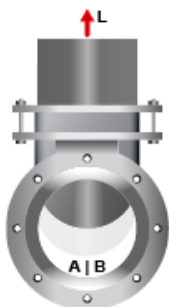
**Library:** Simscape / Fluids / Gas / Valves & Orifices / Flow Control  
Valves



### Description

The Gate Valve (G) block represents an orifice with a translating gate, or *sluice*, as a flow control mechanism. The gate is circular and must slide perpendicular to the flow due to the constraints of the groove of its seat. The seat of the valve is annular. The flow passes through the bore, which is sized to match the gate. The overlap of the gate and the bore determines the opening area of the valve.

This image shows a gate valve with a conical seat.



The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

Gate valves generally open quickly. Gate valves are most sensitive to gate displacement near the closed position, where a small displacement translates into a disproportionately large change in opening area. Consequently, gate valves have too high a gain in that region to effectively throttle or modulate flow. You can use this block as a binary switch to open and close circuits.

### Gate Mechanics

In a real valve, the gate connects by a gear mechanism to a handle. When the handle is turned from a fully closed position, the gate rises from the bore and progressively opens the valve up to a maximum. Hard stops keep the disk from breaching its minimum and maximum positions.

The block captures the motion of the disk but not the detail of its mechanics. You specify the motion as a normalized displacement at port **L**. The input physical signal carries the fraction of the instantaneous displacement over its value in the fully open valve.

If you want to model the action of the handle and hard stop, use Simscape mechanical blocks to capture the displacement signal. However, in many cases, it suffices to know what displacement to impart to the disk and you do not need to model the mechanics of the valve.

### Gate Position

The block models the displacement of the gate but not the valve opening or closing dynamics. The signal at port **L** provides the normalized gate position,  $L$ .  $L$  is a normalized distance between 0 and 1, which indicates a fully closed valve and a fully open valve, respectively. If the calculation returns a number outside of this range, the block sets that number to the nearest bound.

### Numerical Smoothing

When the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized gate position,  $L$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Opening Area

The opening area of the valve is the area of the bore adjusted for the instantaneous overlap of the gate

$$S_{open} = \frac{pD^2}{4} - S_C,$$

where:

- $S_{open}$  is the instantaneous valve opening area. The block then smooths this area to remove derivative discontinuities at the limiting valve positions.
- $D$  is the common diameter of the gate and its bore, which are identical. This is the value of the **Orifice diameter** parameter.
- $S_C$  is the area of overlap between the gate and bore, which the block computes as a function of the gate position,  $L$ :

$$S_C = \frac{D^2}{2} \arccos(L) - \frac{LD}{2} \sqrt{D^2 - L^2 D^2}.$$

The figure shows a front view of the valve when maximally closed, partially open, and fully open, from left to right. The figure also shows the parameters and variables in the opening area calculation.



### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:



- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area based on geometry** — The size of the flow restriction determines the block parameterization.

The block scales the specified flow capacity by the fraction of valve opening. As the fraction of valve opening rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.

### Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v \frac{S_{open}}{S_{Max}} N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}}$$

where:

- $C_v$  is the value of the **Maximum Cv flow coefficient** parameter.
- $S_{open}$  is the valve opening area.
- $S_{Max}$  is the maximum valve area when the valve is fully open.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3p_{in} F_\gamma \chi_T}$$

where:

- $F_\gamma$  is the ratio of the isentropic exponent to 1.4.
- $\chi_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ .

$$\dot{m} = C_v \frac{S_{open}}{S_{Max}} N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{p_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3F_{\gamma} x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma} x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3} C_v \frac{S_{open}}{S_{Max}} N_6 \sqrt{F_{\gamma} x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{p_{out} - B_{crit}}{p_{in} - B_{crit}} \right)^2 \right]^m,$$

where:

- $C$  is the value of the **Maximum sonic conductance** parameter.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} \sqrt{\frac{T_{ref}}{T_{avg}}} \left[ 1 - \left( \frac{B_{lam} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m \left( \frac{p_{in} - p_{out}}{1 - B_{lam}} \right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C \frac{S_{open}}{S_{Max}} \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area based on geometry, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left(\frac{p_{out}}{p_{in}}\right)^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_{open}}{S}\right)^2 \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}}}\right]}$$

where:

- $S_{open}$  is the valve opening area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \left[ \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_{open}}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}}\right] \left( \frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}\right)}$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_{open} \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_{open}}{S}\right)^2}}$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area based on geometry, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to

outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Assumptions and Limitations

- The **Sonic conductance** setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice area** based on geometry parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Input

#### **L – Valve control signal, unitless**

physical signal

Input port through which to specify the relative displacement of the gate as a fraction of its maximum. This input specifies the gate position, which the block uses to compute the mass flow rate through the valve. This position should range between 0 for a maximally closed valve to 1 for a fully open valve.

### Conserving

#### **A – Valve entrance**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve. The direction of flow depends on the pressure differential established across the valve. The block allows both forward and backward directions.

#### **B – Valve entrance**

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve. The direction of flow depends on the pressure differential established across the valve. The block allows both forward and backward directions.

## Parameters

#### **Orifice diameter – Diameter of the bore of the valve**

0.01 m (default) | positive scalar

Diameter of the bore of the valve and of the gate that controls the opening area. The orifice is assumed to be constant in cross section throughout its length from one port to the other.

**Valve parameterization — Parameterization used to specify flow characteristics of orifice**

Orifice area based on geometry (default) | Cv flow coefficient | Kv flow coefficient | Sonic conductance

Method to calculate the mass flow rate.

- Cv flow coefficient — The flow coefficient  $C_v$  determines the block parameterization.
- Kv flow coefficient — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- Sonic conductance — The sonic conductance of the resistive element at steady state determines the block parameterization.
- Orifice area based on geometry — The size of the flow restriction determines the block parameterization.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Orifice area based on geometry.

**Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient.

**xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Maximum value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient.

**Maximum sonic conductance — Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference density — ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Leakage flow fraction — Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B – Flow area at gas ports**0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

**Introduced in R2018b****Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

**Offset parameter removed**

The block no longer has a **Gate displacement fraction offset** parameter and the block no longer offsets the input signal. This change does not impact compatibility.

## References

- [1] ISO 6358-3, "Pneumatic fluid power - Determination of flow-rate characteristics of components using compressible fluids - Part 3: Method for calculating steady-state flow rate characteristics of systems", 2014.
- [2] IEC 60534-2-3, "Industrial-process control valves - Part 2-3: Flow capacity - Test procedures", 2015.
- [3] ANSI/ISA-75.01.01, "Industrial-Process Control Valves - Part 2-1: Flow capacity - Sizing equations for fluid flow underinstalled conditions", 2012.
- [4] P. Beater, *Pneumatic Drives*, Springer-Verlag Berlin Heidelberg, 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Orifice (G) | Poppet Valve (G)



## Gate Valve (TL)

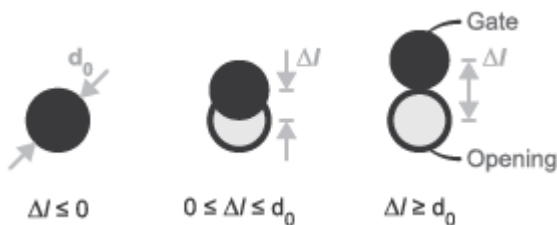
Gate valve in a thermal liquid system

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Flow Control Valves



### Description

The Gate Valve (TL) block represents a gate valve in a thermal liquid network. The valve comprises a round, sharp-edged orifice and a round gate with the same diameter. The gate opens or closes according to the displacement signal at port **S**. A positive signal lifts the gate to open the valve. The diagram shows the relationship between the opening area and the net displacement of the gate.



A smoothing function allows the valve opening area to change smoothly between the fully closed and fully open positions. The smoothing function reduces the abrupt opening area changes at the zero and maximum gate positions.

### Mass Balance

The mass conservation equation in the valve is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate into the valve through port **A**.
- $\dot{m}_B$  is the mass flow rate into the valve through port **B**.

### Momentum Balance

The momentum conservation equation in the valve is

$$p_A - p_B = \frac{\dot{m}\sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{2\rho_{Avg}C_d^2S^2} \left[ 1 - \left( \frac{S_R}{S} \right)^2 \right] PR_{Loss},$$

where:

- $p_A$  and  $p_B$  are the pressures at port **A** and port **B**.
- $\dot{m}$  is the mass flow rate.
- $\dot{m}_{cr}$  is the critical mass flow rate:

$$\dot{m}_{cr} = Re_{cr} \mu_{Avg} \sqrt{\frac{\pi}{4}} S_R.$$

- $\rho_{Avg}$  is the average liquid density.
- $C_d$  is the discharge coefficient.
- $S$  is the valve inlet area.
- $PR_{Loss}$  is the pressure ratio:

$$PR_{Loss} = \frac{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} - C_d(S_R/S)}{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} + C_d(S_R/S)}.$$

### Energy Balance

The energy conservation equation in the valve is

$$\phi_A + \phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate into the valve through port **A**.
- $\phi_B$  is the energy flow rate into the valve through port **B**.

### Valve Opening Area

The block computes the valve opening area by using the expression

$$A = \frac{\pi d_0^2}{4} - A_{Covered},$$

where:

- $A$  is the valve opening area.
- $d_0$  is the valve orifice diameter.
- $A_{Covered}$  is the portion of the valve orifice area covered by the gate:

$$A_{Covered} = \frac{d_0^2}{2} \arccos\left(\frac{\Delta l}{d_0}\right) - \frac{\Delta l}{2} \sqrt{d_0^2 - (\Delta l)^2}.$$

- $\Delta l$  is the net displacement of the gate center relative to the orifice center.

$$\Delta l = \begin{cases} 0, & (S_d - S_{min}) \leq 0 \\ d_0, & (S_d - S_{min}) \geq d_0 \\ (S_d - S_{min}), & \text{Else} \end{cases}$$

- $S_{min}$  is value of the **Gate position when fully covering orifice** parameter specified in the block dialog box.

- $S_a$  is the gate displacement specified through physical signal input port S.

### Numerically Smoothed Displacement

When the valve is in a near-open or near-closed position, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the gate displacement between 0 and the **Valve orifice diameter** parameter. For more information, see “Numerical Smoothing”.

## Ports

### Input

#### S — Gate displacement, m

physical signal

Physical signal port associated with the valve gate displacement, in m. A positive signal retracts the gate and opens the valve.

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port associated with valve inlet A.

#### B — Liquid port

thermal liquid

Thermal liquid conserving port associated with valve inlet B.

## Parameters

#### Orifice diameter — Orifice diameter

0.01 m (default) | positive scalar

Valve open-area diameter.

#### Gate position when fully covering orifice — Gate offset

0 m (default) | nonnegative scalar

Gate offset when the valve is closed. A positive, nonzero value indicates a partially open valve when the signal at port **S** is 0. A negative, nonzero value indicates an overlapped valve that remains closed for an initial positive displacement set by the physical signal at port **S**.

#### Leakage area — Gap area when in fully shut position

1e-12 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully shut position. The block saturates smaller numbers to this value. This parameter contributes to numerical stability by maintaining continuity in the flow.

#### Smoothing factor — Numerical smoothing factor

0.01 (default) | scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions.

**Cross-sectional area at ports A and B — Orifice area at conserving ports**

0.01 m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Discharge coefficient — Discharge coefficient**

0.7 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Poppet Valve (TL)

# Gradual Area Change

Gradual enlargement or contraction

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Local Hydraulic Resistances



## Description

The Gradual Area Change block represents a local hydraulic resistance, such as a gradual cross-sectional area change. The resistance represents a gradual enlargement (diffuser) if fluid flows from inlet to outlet, or a gradual contraction if fluid flows from outlet to inlet. The block is based on the Local Resistance block. It determines the pressure loss coefficient and passes its value to the underlying Local Resistance block. The block offers two methods of parameterization: by applying semi-empirical formulas (with a constant value of the pressure loss coefficient) or by table lookup for the pressure loss coefficient based on the Reynolds number.

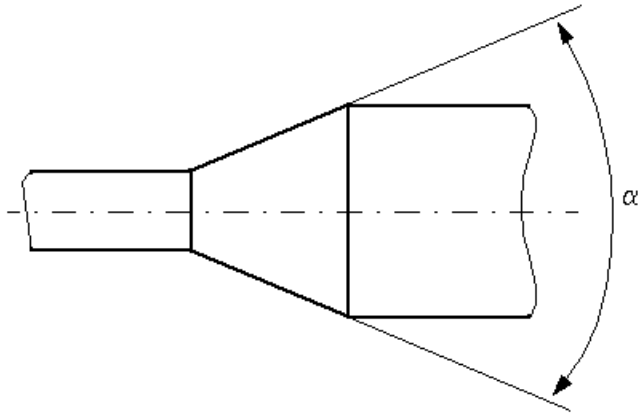
If you choose to apply the semi-empirical formulas, you provide geometric parameters of the resistance, and the pressure loss coefficient is determined according to the A.H. Gibson equations (see [1] and [2]):

$$K_{GE} = \begin{cases} K_{cor} \left(1 - \frac{A_s}{A_L}\right)^2 \cdot 2.6 \sin \frac{\alpha}{2} & \text{for } 0 < \alpha \leq 45^\circ \\ K_{cor} \left(1 - \frac{A_s}{A_L}\right)^2 & \text{for } 45^\circ < \alpha < 180^\circ \end{cases}$$

$$K_{GC} = \begin{cases} K_{cor} \cdot 0.5 \left(1 - \frac{A_s}{A_L}\right)^{0.75} \cdot 1.6 \sin \frac{\alpha}{2} & \text{for } 0 < \alpha \leq 45^\circ \\ K_{cor} \cdot 0.5 \left(1 - \frac{A_s}{A_L}\right)^{0.75} \cdot \sqrt{\sin \frac{\alpha}{2}} & \text{for } 45^\circ < \alpha < 180^\circ \end{cases}$$

where

$K_{GE}$	Pressure loss coefficient for the gradual enlargement, which takes place if fluid flows from inlet to outlet
$K_{GC}$	Pressure loss coefficient for the gradual contraction, which takes place if fluid flows from outlet to inlet
$K_{cor}$	Correction factor
$A_s$	Small area
$A_L$	Large area
$\alpha$	Enclosed angle



If you choose to specify the pressure loss coefficient by a table, you have to provide a tabulated relationship between the loss coefficient and the Reynolds number. In this case, the loss coefficient is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

The pressure loss coefficient, determined by either of the two methods, is then passed to the underlying Local Resistance block, which computes the pressure loss according to the formulas explained in the reference documentation for that block. The flow regime is checked in the underlying Local Resistance block by comparing the Reynolds number to the specified critical Reynolds number value, and depending on the result, the appropriate formula for pressure loss computation is used.

The Gradual Area Change block is bidirectional and computes pressure loss for both the direct flow (gradual enlargement) and return flow (gradual contraction). If the loss coefficient is specified by a table, the table must cover both the positive and the negative flow regions.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

## Assumptions and Limitations

- Fluid inertia is not taken into account.
- If you select parameterization by the table-specified relationship  $K=f(Re)$ , the flow is assumed to be turbulent.

## Ports

### Conserving

#### A — Hydraulic conserving port associated with the resistance inlet

hydraulic

Hydraulic conserving port associated with the resistance inlet. This is the port with the smaller cross-sectional area.

#### B — Hydraulic conserving port associated with the resistance outlet

hydraulic

Hydraulic conserving port associated with the resistance outlet. This is the port with the larger cross-sectional area.

## Parameters

### Model parameterization — Select method of block parameterization

Semi-empirical correlation (default) | Tabulated data – loss coefficient vs. Reynolds number

Select one of the following methods for block parameterization:

- Semi-empirical correlation — Provide geometrical parameters of the resistance.
- Tabulated data – loss coefficient vs. Reynolds number — Provide tabulated relationship between the loss coefficient and the Reynolds number. The loss coefficient is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods. The table must cover both the positive and the negative flow regions.

### Small diameter — Internal diameter at the inlet port

0.01 m (default) | positive scalar

Internal diameter at the small port, **A**.

### Large diameter — Internal diameter at the outlet port

0.02 m (default) | positive scalar

Internal diameter at the large port, **B**.

### Dependencies

To enable this parameter, set **Model parameterization** to Semi-empirical correlation.

### Cone angle — Enclosed angle

30 deg (default) | scalar in the range of (0,180 deg)

The enclosed angle.

### Dependencies

To enable this parameter, set **Model parameterization** to Semi-empirical correlation.

### Correction coefficient — Correction factor for computation of the loss coefficient

1 (default) | positive scalar

Correction factor used in the formula for computation of the loss coefficient.

### Dependencies

To enable this parameter, set **Model parameterization** to Semi-empirical correlation.

### Laminar transition specification — Select how block transitions between the laminar and turbulent regimes

Pressure ratio (default) | Reynolds number

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Dependencies**

To enable this parameter, set **Model parameterization** to `Semi-empirical correlation`.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | scalar in the range of (0,1)

Pressure ratio at which the flow transitions between laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Laminar transition specification** to `Pressure ratio`.

**Critical Reynolds number — Maximum Reynolds number for laminar flow**

350 (default) | scalar

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks.

**Dependencies**

To enable this parameter, set **Laminar transition specification** to `Reynolds number`.

**Reynolds number vector — Vector of input values for Reynolds numbers**

[-4000, -3000, -2000, -1000, -500, -200, -100, -50, -40, -30, -20, -15, -10, 10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000, 4000, 5000, 10000] (default) | 1-by-*n* vector

Specify the vector of input values for Reynolds numbers as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation.

**Dependencies**

To enable this parameter, set **Model parameterization** to `Tabulated data – loss coefficient vs. Reynolds number`.

**Loss coefficient vector — Vector of the loss coefficient values**

[0.25, 0.3, 0.65, 0.9, 0.65, 0.75, 0.90, 1.15, 1.35, 1.65, 2.3, 2.8, 3.10, 5, 2.7, 1.8, 1.46, 1.3, 0.9, 0.65, 0.42, 0.3, 0.20, 0.40, 0.42, 0.25] (default) | 1-by-*n* vector

Specify the vector of the loss coefficient values as a one-dimensional array. The loss coefficient vector must be of the same size as the Reynolds numbers vector.



### Dependencies

To enable this parameter, set **Model parameterization** to Tabulated data – loss coefficient vs. Reynolds number.

### Interpolation method – Select the interpolation method

Linear (default) | Smooth

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** – Select this option to get the best performance.
- **Smooth** – Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see PS Lookup Table (1D).

### Dependencies

To enable this parameter, set **Model parameterization** to Tabulated data – loss coefficient vs. Reynolds number.

### Extrapolation method – Select the extrapolation method

Linear (default) | Nearest

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** – Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** – Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see PS Lookup Table (1D).

### Dependencies

To enable this parameter, set **Model parameterization** to Tabulated data – loss coefficient vs. Reynolds number.

## Version History

Introduced in R2006b

## References

[1] *Flow of Fluids Through Valves, Fittings, and Pipe*, Crane Valves North America, Technical Paper No. 410M

[2] Idelchik, I.E., *Handbook of Hydraulic Resistance*, CRC Begell House, 1994

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Elbow | Local Resistance | Pipe Bend | Sudden Area Change | T-junction

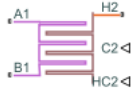
### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Heat Exchanger (G)

Heat exchanger for systems with gas and controlled flows

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (G) block models heat exchange between a gas, which flows between ports **A1** and **B1**, and an external, *controlled* fluid via a physical signal. The physical signal ports **C2** and **HC2** are exposed when heat exchange is calculated according to the E-NTU model. The physical signal ports **CP2** and **M2** are exposed when heat exchange is calculated according to the Simple model.

You can set the E-NTU or Simple block variant by using the **Modeling option** parameter to set your preferred heat exchange model.



### The E-NTU Model

The default variant. Its heat transfer model derives from the Effectiveness-NTU method. Heat transfer in the steady state then proceeds at a fraction of the ideal rate which the flows, if kept each at its inlet temperature, and if cleared of every thermal resistance in between, could in theory support:

$$Q_{\text{Act}} = \epsilon Q_{\text{Max}}$$

where  $Q_{\text{Act}}$  the actual heat transfer rate,  $Q_{\text{Max}}$  is the ideal heat transfer rate, and  $\epsilon$  is the fraction of the ideal rate actually observed in a real heat exchanger encumbered with losses. The fraction is the heat exchanger effectiveness, and it is a function of the number of transfer units, or NTU, a measure of the ease with which heat moves between flows, relative to the ease with which the flows absorb that heat:

$$NTU = \frac{1}{RC_{\text{Min}}},$$

where the fraction is the overall thermal conductance between the flows and  $C_{\text{Min}}$  is the smallest of the heat capacity rates from among the flows—that belonging to the flow least capable of absorbing

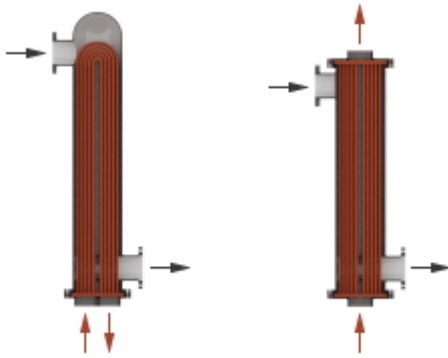
heat. The heat capacity rate of a flow depends on the specific heat of the fluid ( $c_p$ ) and on its mass flow rate through the exchanger ( $\dot{m}$ ):

$$C = c_p \dot{m}.$$

The effectiveness depends also on the relative disposition of the flows, the number of passes between them, and the mixing condition for each. This dependence reflects in the effectiveness expression used, with different flow arrangements corresponding to different expressions. For a list of the effectiveness expressions, see the E-NTU Heat Transfer block.

### Flow Arrangement

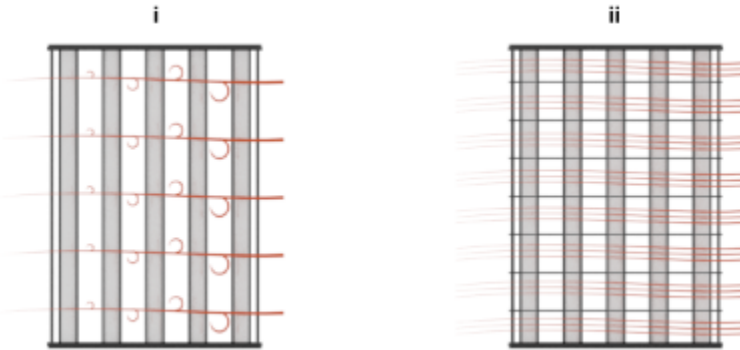
Use the **Flow arrangement** block parameter to set how the flows meet in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those same tubes. The figure shows an example. The tube flow can make one pass through the shell flow (shown right) or, for greater exchanger effectiveness, multiple passes (left).



Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger, are assumed to manifest in the tabulated data.

### Mixing Condition

Use the **Cross flow type** parameter to mix each of the flows, one of the flows, or none of the flows. Mixing in this context is the lateral movement of fluid in channels that have no internal barriers, normally guides, baffles, fins, or walls. Such movement serves to even out temperature variations in the transverse plane. Mixed flows have variable temperature in the longitudinal plane alone. Unmixed flows have variable temperature in both the transverse and longitudinal planes. The figure shows a mixed flow (i) and an unmixed flow (ii).

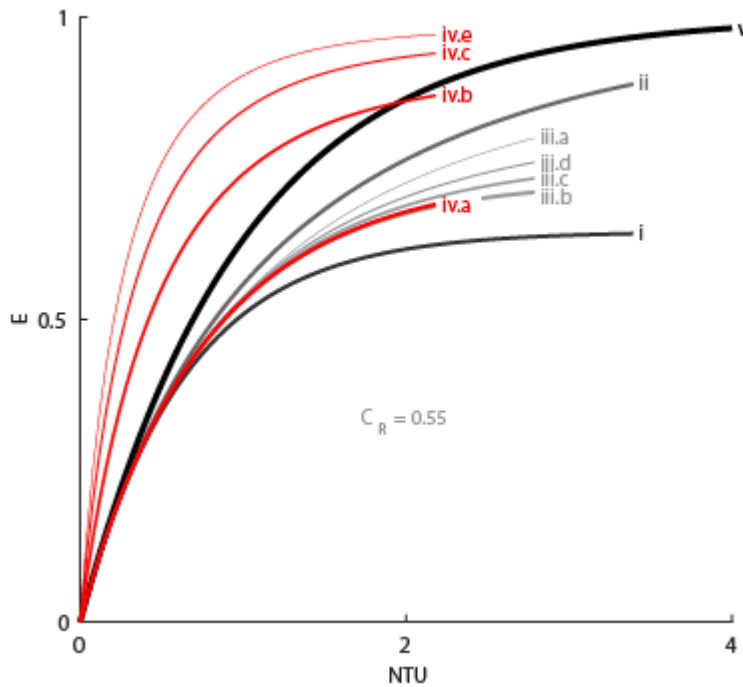


The distinction between mixed and unmixed flows is considered only in cross flow arrangements. There, longitudinal temperature variation in one fluid produces transverse temperature variation in the second fluid that mixing can even out. In counter and parallel flow arrangements, longitudinal temperature variation in one fluid produces longitudinal temperature variation in the second fluid and mixing, as it is of little effect here, is ignored.

#### Effectiveness Curves

Shell-and-tube exchangers with multiple passes (**iv.b-e** in the figure for 2, 3, and 4 passes) are most effective. Of exchangers with a single pass, those with counter flows (**ii**) are most effective and those with parallel flows (**i**) are least.

Cross-flow exchangers are intermediate in effectiveness, with mixing condition playing a factor. They are most effective when both flows are unmixed (**iii.a**) and least effective when both flows are mixed (**iii.b**). Mixing just the flow with the smallest heat capacity rate (**iii.c**) lowers the effectiveness more than mixing just the flow with the largest heat capacity rate (**iii.d**).

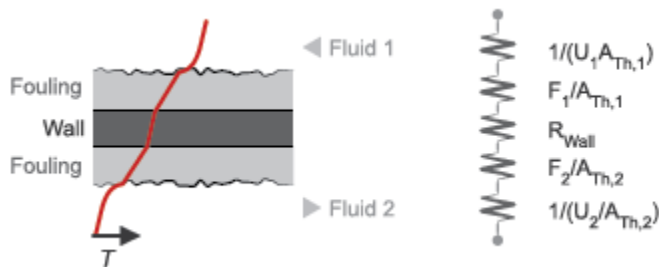


**Thermal Resistance**

The overall thermal resistance,  $R$ , is the sum of the local resistances lining the heat transfer path. The local resistances arise from convection at the surfaces of the wall, conduction through the wall, and, if the wall sides are fouled, conduction through the layers of fouling. Expressed in order from the gas side (subscript 1) to the controlled fluid side (subscript 2):

$$R = \frac{1}{U_1 A_{Th,1}} + \frac{F_1}{A_{Th,1}} + R_{Wall} + \frac{F_2}{A_{Th,2}} + \frac{1}{U_2 A_{Th,2}}$$

where  $U$  is the convective heat transfer coefficient,  $F$  is the fouling factor, and  $A_{Th}$  is the heat transfer surface area, each for the flow indicated in the subscript.  $R_W$  is the thermal resistance of the wall.

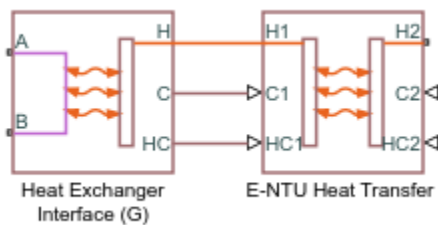


The wall thermal resistance and fouling factors are simple constants obtained from block parameters. The heat transfer coefficients are elaborate functions of fluid properties, flow geometry, and wall friction, and derive from standard empirical correlations between Reynolds, Nusselt, and Prandtl

numbers. The correlations depend on flow arrangement and mixing condition, and are detailed for each in the E-NTU Heat Transfer block on which the E-NTU Model variant is based.

### Composite Structure

The E-NTU Model variant is a composite component built from simpler blocks. A Heat Exchanger Interface (G) block models the gas flow. Physical signals for the heat capacity rate and heat transfer coefficient, along with a thermal port for temperature, capture the controlled flow. An E-NTU Heat Transfer block models the heat exchanged across the wall between the flows. The figure shows the block connections for the E-NTU Model block variant.



### The Simple Model

The alternative variant. Its heat transfer model depends on the concept of *specific dissipation*, a measure of the heat transfer rate observed when gas and controlled fluid inlet temperatures differ by one degree. Its product with the inlet temperature difference gives the expected heat transfer rate:

$$Q = \xi(T_{\text{In},1} - T_{\text{In},2}),$$

where  $\xi$  is specific dissipation and  $T_{\text{In}}$  is inlet temperature for gas (subscript 1) or controlled fluid (subscript 2). The specific dissipation is a tabulated function of the mass flow rates into the exchanger through the gas and controlled fluid inlets:

$$\xi = f(\dot{m}_1, \dot{m}_2)$$

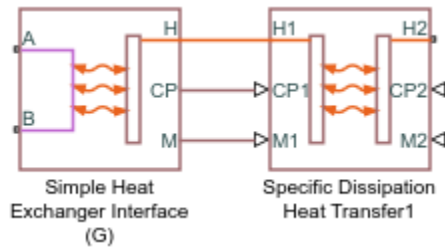
To accommodate reverse flows, the tabulated data can extend over positive and negative flow rates, in which case the inlets can also be thought of as outlets. The data normally derives from measurement of heat transfer rate against temperature in a real prototype:

$$\xi = \frac{Q}{T_{\text{In},1} - T_{\text{In},2}}$$

The heat transfer model, as it relies almost entirely on tabulated data, and as that data normally derives from experiment, requires little detail about the exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger modeled, are assumed to manifest entirely in the tabulated data.

### Composite Structure

The Simple Model variant is a composite component. A Simple Heat Exchanger Interface (G) block models the gas flow. Physical signals for the heat transfer coefficient and mass flow rate, along with a thermal port for temperature, capture the controlled flow. A Specific Dissipation Heat Transfer block models the heat exchanged across the wall between the flows.



## Ports

### Conserving

#### A1 — Gas port

gas

Opening for gas to enter and exit its side of the heat exchanger.

#### B1 — Gas port

gas

Opening for gas to enter and exit its side of the heat exchanger.

### Input

#### C2 — Heat capacity rate

physical signal

Instantaneous value of the heat capacity rate for the controlled flow.

#### Dependencies

This port is active only for the block variant of E-NTU Model.

#### HC2 — Heat transfer coefficient

physical signal

Instantaneous value of the heat transfer coefficient between the controlled flow and the wall.

#### Dependencies

This port is active only for the block variant of E-NTU Model.

#### CP2 — Isobaric specific heat of controlled fluid

physical signal

Instantaneous value of the isobaric specific heat for the controlled fluid.

#### Dependencies

This port is active only for the block variant of Simple Model.

#### M2 — Mass flow rate of controlled fluid

physical signal

Instantaneous value of the mass flow rate of the controlled fluid.



## Dependencies

This port is active only for the block variant of Simple Model.

## Parameters

### Modeling option — Heat transfer model

E-NTU Model | Simple model

Set the heat transfer model for the block.

### Block Variant: Simple Model

#### Heat Transfer Tab

### Gas mass flow rate vector — Mass flow rate of gas at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of gas at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB linear type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

### Controlled fluid mass flow rate vector — Mass flow rate of controlled fluid at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of controlled fluid at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB linear type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

### Specific heat dissipation table — Specific heat dissipation at each breakpoint in lookup table over mass flow rates of gas and controlled fluid

numerical array with units of power over temperature

Specific heat dissipation at each breakpoint in its lookup table over the mass flow rates of gas and controlled fluid. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of gas and controlled fluid mass flow rates. Interpolation is the MATLAB linear type and extrapolation is nearest.

The specific heat dissipation values must not be negative. They must align from top to bottom in order of increasing mass flow rate in the gas channel, and from left to right in order of increasing mass flow rate in the controlled fluid channel. The number of rows must equal the size of the **Gas mass flow rate vector** parameter, and the number of columns must equal the size of the **Controlled fluid mass flow rate vector** parameter.

**Check if violating maximum specific dissipation — Warning condition for specific heat dissipation in excess of minimum heat capacity rate**

Warning (default) | None

Warning condition for specific heat dissipation in excess of minimum heat capacity rate. Heat capacity rate is the product of mass flow rate and specific heat, and its minimum value is the lowest between the flows. This minimum gives the specific dissipation for a heat exchanger with maximum effectiveness and cannot be exceeded. See the Specific Dissipation Heat Transfer block for more detail.

**Pressure Loss Tab****Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop**

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Pressure drop vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate**

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Mass flow rate vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Reference inflow temperature — Absolute inlet temperature assumed in tabulated data**

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Reference inflow pressure — Absolute inlet pressure assumed in tabulated data**

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Mass flow rate threshold for flow reversal – Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities known to produce simulation errors at zero flow. See the Simple Heat Exchanger Interface (G) block (on which the Simple Model variant is based) for detail on the calculations for the gas side of the exchanger.

**Gas volume – Volume of fluid in the gas flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the gas flow channel.

**Cross-sectional area at ports A1 and B1 – Flow area at the inlet and outlet of the flow channel**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the gas flow channel. The ports are of the same size.

**Block Variant: E-NTU Model****Common Tab****Flow arrangement – Manner in which the flows align in the heat exchanger**

Parallel or counter flow (default) | Shell and tube | Cross flow | Generic - effectiveness table

Manner in which the flows align in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those tubes. Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger.

**Number of shell passes – Number of times the flow traverses the shell before exiting**

1 (default) | unitless scalar

Number of times the flow traverses the shell before exiting.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Cross flow type – Mixing condition in each of the flow channels**

Both fluids mixed (default) | Both fluids unmixed | Gas mixed & Controlled Fluid unmixed | Gas unmixed & Controlled Fluid mixed

Mixing condition in each of the flow channels. Mixing in this context is the lateral movement of fluid as it proceeds along its flow channel toward the outlet. The flows remain separate from each other. Unmixed flows are common in channels with plates, baffles, or fins. This setting reflects in the effectiveness of the heat exchanger, with unmixed flows being most effective and mixed flows being least.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Number of heat transfer units vector, NTU — Number of transfer units at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Number of transfer units at each breakpoint in the lookup table for the heat exchanger effectiveness number. The table is two-way, with both the number of transfer units and the thermal capacity ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any number of transfer units. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The numbers specified must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of rows in the **Effectiveness table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the number of transfer units must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Thermal capacity ratio vector, CR — Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness. The table is two-way, with both the number of transfer units and the heat capacity rate ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The thermal capacity ratios must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the thermal capacity ratio must be  $n$  elements long. The thermal capacity ratio is the fraction of minimum over maximum heat capacity rates.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Effectiveness table, E(NTU, CR) — Heat exchanger effectiveness at each breakpoint in lookup table over the number of transfer units and thermal capacity ratio**

unitless numerical array

Heat exchanger effectiveness at each breakpoint in its lookup table over the number of transfer units and thermal capacity ratio. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of number of transfer units and thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The effectiveness values must be not be negative. They must align from top to bottom in order of increasing number of transfer units and from left to right in order of increasing thermal capacity ratio. The number of rows must equal the size of the **Number of heat transfer units vector** parameter, and the number of columns must equal the size of the **Thermal capacity ratio vector** parameter.

## Dependencies

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

### Wall thermal resistance — Resistance of the wall to heat flow by thermal conduction

1.6e-4 K/W (default) | scalar with units of temperature over power

Resistance of the wall to heat flow by thermal conduction, and the inverse of thermal conductance, or the product of thermal conductivity with the ratio of surface area to length. Wall resistance adds to convective and fouling resistances to determine the overall heat transfer coefficient between the flows.

## Gas Tab

### Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Cross-sectional area of the flow channel at its narrowest point. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum of the areas in the collection—minus the occlusion due to walls, ridges, plates, or other barriers.

### Gas volume — Total volume of fluid in the gas flow channel

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Total volume of fluid contained in the gas flow channel.

### Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

### Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

### Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones

4000 (default) | unitless scalar

End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (G) block for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet — Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances — Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness – Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor – Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor – Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block interpolates and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### **Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Darcy friction factor vs. Reynolds number`.

#### **Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### **Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Euler number vs. Reynolds number`.

#### **Euler number vector – Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

#### **Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Euler number vs. Reynolds number`.

#### **Heat transfer parameterization – Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number



Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area – Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Gas-wall heat transfer coefficient – Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer – Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length traversed in heat transfer between fluid and wall. This length factors in the calculation of the hydraulic diameter from which the heat transfer coefficient and the Reynolds number, as defined in the tabulated heat transfer parameterizations, derives.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.

**Reynolds number vector for Colburn factor – Values of the Reynolds number at which to specify the Colburn factor data**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block inter- and extrapolates the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

#### Colburn factor vector – Colburn factor at each breakpoint in lookup table over Reynolds number

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

#### Reynolds number vector for Nusselt number – Reynolds number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### Prandtl number vector for Nusselt number – Prandtl number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and

extrapolates the breakpoints to obtain the Nusselt number at any Prandtl number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### **Nusselt number table, Nu (Re,Pr) – Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### **Fouling factor – Measure of thermal resistance due to fouling deposits**

$1.6e-4$  K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

#### **Minimum fluid-wall heat transfer coefficient – Lower bound for the heat transfer coefficient**

$100$  W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

#### Controlled Fluid Tab

#### **Heat transfer surface area – Aggregate heat transfer surface area on the controlled fluid side**

$0.4$  m<sup>2</sup> (default) | scalar with units of length squared

Aggregate heat transfer surface area on the controlled fluid side

**Fouling factor — Measure of thermal resistance due to fouling deposits**

1e-4 K/W (default) | scalar with units of length squared times temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the controlled fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**

100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between the controlled fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

**Effects and Initial Conditions****Gas initial temperature — Temperature in the gas channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the gas channel at the start of simulation.

**Gas initial pressure — Pressure in the gas channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the gas channel at the start of simulation.

## Version History

Introduced in R2017b

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

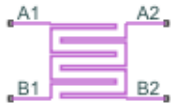
## See Also

E-NTU Heat Transfer | Heat Exchanger Interface (G) | Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (G)

## Heat Exchanger (G-G)

Heat exchanger for systems with two gas flows

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (G-G) block models a gas-gas heat exchanger. The wall can store heat in its bounds, adding to the heat transfer a slight transient delay that scales in proportion to its thermal mass. The fluids are single phase—each a gas. Neither fluid can switch phase and so, as latent heat is never released, the exchange is strictly one of sensible heat.



### Block Variants

The heat transfer model depends on the choice of block variant. The block has two variants: E-NTU Model and Simple Model. Use the **Modeling option** parameter to change the variant.

#### E-NTU Model

The default variant. Its heat transfer model derives from the Effectiveness-NTU method. Heat transfer in the steady state then proceeds at a fraction of the ideal rate which the flows, if kept each at its inlet temperature, and if cleared of every thermal resistance in between, could in theory support:

$$Q_{\text{Act}} = \epsilon Q_{\text{Max}}$$

where  $Q_{\text{Act}}$  the actual heat transfer rate,  $Q_{\text{Max}}$  is the ideal heat transfer rate, and  $\epsilon$  is the fraction of the ideal rate actually observed in a real heat exchanger encumbered with losses. The fraction is the heat exchanger effectiveness, and it is a function of the number of transfer units, or NTU, a measure of the ease with which heat moves between flows, relative to the ease with which the flows absorb that heat:

$$NTU = \frac{1}{RC_{\text{Min}}},$$

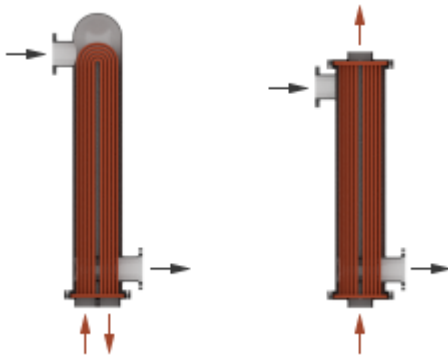
where the fraction is the overall thermal conductance between the flows and  $C_{\text{Min}}$  is the smallest of the heat capacity rates from among the flows—that belonging to the flow least capable of absorbing heat. The heat capacity rate of a flow depends on the specific heat of the fluid ( $c_p$ ) and on its mass flow rate through the exchanger ( $\dot{m}$ ):

$$C = c_p \dot{m}.$$

The effectiveness depends also on the relative disposition of the flows, the number of passes between them, and the mixing condition for each. This dependence reflects in the effectiveness expression used, with different flow arrangements corresponding to different expressions. For a list of the effectiveness expressions, see the E-NTU Heat Transfer block.

### Flow Arrangement

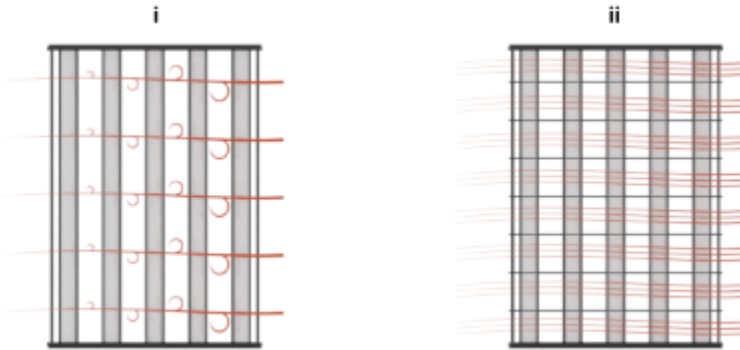
Use the **Flow arrangement** block parameter to set how the flows meet in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those same tubes. The figure shows an example. The tube flow can make one pass through the shell flow (shown right) or, for greater exchanger effectiveness, multiple passes (left).



Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger, are assumed to manifest in the tabulated data.

### Mixing Condition

Use the **Cross flow type** parameter to mix each of the flows, one of the flows, or none of the flows. Mixing in this context is the lateral movement of fluid in channels that have no internal barriers, normally guides, baffles, fins, or walls. Such movement serves to even out temperature variations in the transverse plane. Mixed flows have variable temperature in the longitudinal plane alone. Unmixed flows have variable temperature in both the transverse and longitudinal planes. The figure shows a mixed flow (**i**) and an unmixed flow (**ii**).

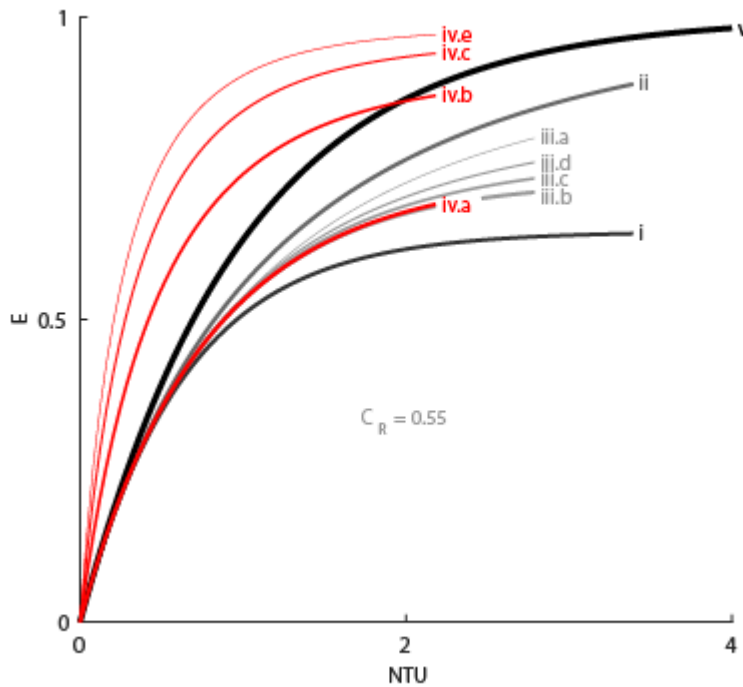


The distinction between mixed and unmixed flows is considered only in cross flow arrangements. There, longitudinal temperature variation in one fluid produces transverse temperature variation in the second fluid that mixing can even out. In counter and parallel flow arrangements, longitudinal temperature variation in one fluid produces longitudinal temperature variation in the second fluid and mixing, as it is of little effect here, is ignored.

#### Effectiveness Curves

Shell-and-tube exchangers with multiple passes (**iv.b-e** in the figure for 2, 3, and 4 passes) are most effective. Of exchangers with a single pass, those with counter flows (**ii**) are most effective and those with parallel flows (**i**) are least.

Cross-flow exchangers are intermediate in effectiveness, with mixing condition playing a factor. They are most effective when both flows are unmixed (**iii.a**) and least effective when both flows are mixed (**iii.b**). Mixing just the flow with the smallest heat capacity rate (**iii.c**) lowers the effectiveness more than mixing just the flow with the largest heat capacity rate (**iii.d**).

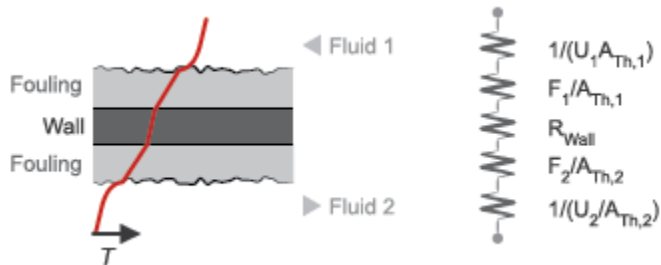


**Thermal Resistance**

The overall thermal resistance,  $R$ , is the sum of the local resistances lining the heat transfer path. The local resistances arise from convection at the surfaces of the wall, conduction through the wall, and, if the wall sides are fouled, conduction through the layers of fouling. Expressed in order from gas side 1 to gas side 2:

$$R = \frac{1}{U_1 A_{Th,1}} + \frac{F_1}{A_{Th,1}} + R_{Wall} + \frac{F_2}{A_{Th,2}} + \frac{1}{U_2 A_{Th,2}}$$

where  $U$  is the convective heat transfer coefficient,  $F$  is the fouling factor, and  $A_{Th}$  is the heat transfer surface area, each for the flow indicated in the subscript.  $R_W$  is the thermal resistance of the wall.



The wall thermal resistance and fouling factors are simple constants obtained from block parameters. The heat transfer coefficients are elaborate functions of fluid properties, flow geometry, and wall friction, and derive from standard empirical correlations between Reynolds, Nusselt, and Prandtl



numbers. The correlations depend on flow arrangement and mixing condition, and are detailed for each in the E-NTU Heat Transfer block on which the E-NTU Model variant is based.

### Thermal Mass

The wall is more than a thermal resistance for heat to pass through. It is also a thermal mass and, like the flows it divides, it can store heat in its bounds. The storage slows the transition between steady states so that a thermal perturbation on one side does not promptly manifest on the side across. The lag persists for the short time that it takes the heat flow rates from the two sides to balance each other. That time interval scales with the thermal mass of the wall:

$$C_{Q,W} = c_{p,W}M_W,$$

where  $c_{p,W}$  is the specific heat capacity and  $M_W$  the inertial mass of the wall. Their product gives the energy required to raise wall temperature by one degree. Use the **Wall thermal mass** block parameter to specify that product. The parameter is active when the **Wall thermal dynamics** setting is On.

Thermal mass is often negligible in low-pressure systems. Low pressure affords a thin wall with a transient response so fast that, on the time scale of the heat transfer, it is virtually instantaneous. The same is not true of high-pressure systems, common in the production of ammonia by the Haber process, where pressure can break 200 atmospheres. To withstand the high pressure, the wall is often thicker, and, as its thermal mass is heftier, so its transient response is slower.

Set the **Wall thermal dynamics** parameter to Off to ignore the transient lag, cut the differential variables that produce it, and, in reducing calculations, speed up the rate of simulation. Leave it On to capture the transient lag where it has a measurable effect. Experiment with the setting if necessary to determine whether to account for thermal mass. If simulation results differ to a considerable degree, and if simulation speed is not a factor, keep the setting On.

The wall, if modeled with thermal mass, is considered in halves. One half sits on gas side 1 and the other half sits on gas side 2. The thermal mass divides evenly between the pair:

$$C_{Q,1} = C_{Q,2} = \frac{C_{Q,W}}{2}.$$

Energy is conserved in the wall. In the simple case of a wall half at steady state, heat gained from the fluid equals heat lost to the second half. The heat flows at the rate predicted by the E-NTU method for a wall without thermal mass. The rate is positive for heat flows directed from side 1 of the heat exchanger to side 2:

$$Q_1 = -Q_2 = \epsilon Q_{\text{Max}}.$$

In the transient state, the wall is in the course of storing or losing heat, and heat gained by one half no longer equals that lost to the second half. The difference in the heat flow rates varies over time in proportion to the rate at which the wall stores or loses heat. For side 1 of the heat exchanger:

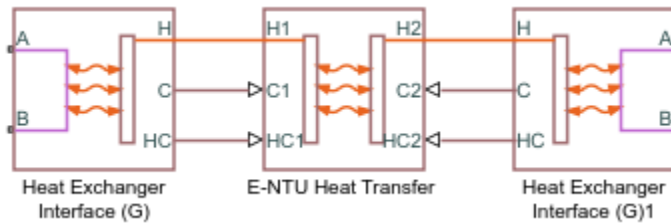
$$Q_1 = \epsilon Q_{\text{Max}} + C_{Q,1}\dot{T}_{W,1},$$

where  $\dot{T}_{W,1}$  is the rate of change in temperature in the wall half. Its product with the thermal mass of the wall half gives the rate at which heat accumulates there. That rate is positive when temperature rises and negative when it drops. The closer the rate is to zero the closer the wall is to steady state.

For side 2 of the heat exchanger:  $Q_2 = -\epsilon Q_{\text{Max}} + C_{Q,2}\dot{T}_{W,2}$ ,

### Composite Structure

The E-NTU Model variant is a composite component built from simpler blocks. A Heat Exchanger Interface (G) block models the gas flow on side 1 of the heat exchanger. Another models the gas flow on side 2. An E-NTU Heat Transfer block models the heat exchanged across the wall between the flows. The figure shows the block connections for the E-NTU Model block variant.



### Simple Model

The alternative variant. Its heat transfer model depends on the concept of *specific dissipation*, a measure of the heat transfer rate observed when gas 1 and gas 2 inlet temperatures differ by one degree. Its product with the inlet temperature difference gives the expected heat transfer rate:

$$Q = \xi(T_{In,1} - T_{In,2}),$$

where  $\xi$  is specific dissipation and  $T_{In}$  is inlet temperature for gas 1 (subscript 1) or gas 2 (subscript 2). The specific dissipation is a tabulated function of the mass flow rates into the exchanger through the gas 1 and gas 2 inlets:

$$\xi = f(\dot{m}_1, \dot{m}_2)$$

To accommodate reverse flows, the tabulated data can extend over positive and negative flow rates, in which case the inlets can also be thought of as outlets. The data normally derives from measurement of heat transfer rate against temperature in a real prototype:

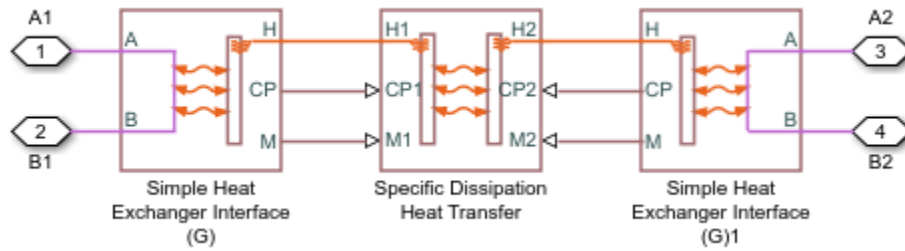
$$\xi = \frac{Q}{T_{In,1} - T_{In,2}}$$

The heat transfer model, as it relies almost entirely on tabulated data, and as that data normally derives from experiment, requires little detail about the exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger modeled, are assumed to manifest entirely in the tabulated data.

See the Specific Dissipation Heat Transfer block for more detail on the heat transfer calculations.

### Composite Structure

The Simple Model variant is a composite component. A Simple Heat Exchanger Interface (G) block models the gas flow on side 1 of the heat exchanger. Another models the gas flow on side 2. A Specific Dissipation Heat Transfer block captures the heat exchanged across the wall between the flows.



## Ports

### Conserving

#### A1 — Gas 1 port

gas

Opening for gas 1 to enter and exit its side of the heat exchanger.

#### B1 — Gas 1 port

gas

Opening for gas 1 to enter and exit its side of the heat exchanger.

#### A2 — Gas 2 port

gas

Opening for gas 2 to enter and exit its side of the heat exchanger.

#### B2 — Gas 2 port

gas

Opening for gas 2 to enter and exit its side of the heat exchanger.

## Parameters

### Modeling option — Heat transfer model

E-NTU Model | Simple model

Set the heat transfer model for the block.

### Block Variant: Simple Model

#### Heat Transfer Tab

#### Gas 1 mass flow rate vector — Mass flow rate of gas 1 at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of gas 1 at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB linear type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

**Gas 2 mass flow rate vector — Mass flow rate of gas 2 at each breakpoint in lookup table for specific heat dissipation table**

numerical array with units of mass over time

Mass flow rate of gas 2 at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

**Specific heat dissipation table — Specific heat dissipation at each breakpoint in lookup table over mass flow rates of gas 1 and gas 2**

numerical array with units of power over temperature

Specific heat dissipation at each breakpoint in its lookup table over the mass flow rates of gas 1 and gas 2. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of gas 1 and gas 2 mass flow rates. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The specific heat dissipation values must not be negative. They must align from top to bottom in order of increasing mass flow rate in the gas 1 channel, and from left to right in order of increasing mass flow rate in the gas 2 channel. The number of rows must equal the size of the **Gas 1 mass flow rate vector** parameter, and the number of columns must equal the size of the **Gas 2 mass flow rate vector** parameter.

**Check if violating maximum specific dissipation — Warning condition for specific heat dissipation in excess of minimum heat capacity rate**

Warning (default) | None

Warning condition for specific heat dissipation in excess of minimum heat capacity rate. Heat capacity rate is the product of mass flow rate and specific heat, and its minimum value is the lowest between the flows. This minimum gives the specific dissipation for a heat exchanger with maximum effectiveness and cannot be exceeded. See the Specific Dissipation Heat Transfer block for more detail.

**Gas 1|2 Tab**

**Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop**

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Pressure drop vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate**

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Mass flow rate vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Reference inflow temperature — Absolute inlet temperature assumed in tabulated data**

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Reference inflow pressure — Absolute inlet pressure assumed in tabulated data**

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Threshold mass flow rate for flow reversal — Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities known to produce simulation errors at zero flow. See the Simple Heat Exchanger Interface (G) block (on which the Simple Model variant is based) for detail on the calculations.

**Fluid volume — Volume of fluid in the gas 1 or gas 2 flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the gas 1 or gas 2 flow channel.

**Cross-sectional area at ports A and B — Flow area at the inlet and outlet of the flow channel**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the gas 1 or gas 2 flow channel. Ports in the same flow channel are of the same size.

**Block Variant: E-NTU Model****Common Tab****Flow arrangement — Manner in which the flows align in the heat exchanger**

Parallel or counter flow (default) | Shell and tube | Cross flow | Generic - effectiveness table

Manner in which the flows align in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those tubes. Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger.

**Number of shell passes — Number of times the flow traverses the shell before exiting**

1 (default) | unitless scalar

Number of times the flow traverses the shell before exiting.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Cross flow type — Mixing condition in each of the flow channels**

Both fluids mixed (default) | Both fluids unmixed | Gas 1 mixed & Gas 2 unmixed | Gas 1 unmixed & Gas 2 mixed

Mixing condition in each of the flow channels. Mixing in this context is the lateral movement of fluid as it proceeds along its flow channel toward the outlet. The flows remain separate from each other. Unmixed flows are common in channels with plates, baffles, or fins. This setting reflects in the effectiveness of the heat exchanger, with unmixed flows being most effective and mixed flows being least.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Number of heat transfer units vector, NTU — Number of transfer units at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Number of transfer units at each breakpoint in the lookup table for the heat exchanger effectiveness number. The table is two-way, with both the number of transfer units and the thermal capacity ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any number of transfer units. Interpolation is the MATLAB linear type and extrapolation is nearest.

The numbers specified must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of rows in the **Effectiveness table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the number of transfer units must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Thermal capacity ratio vector, CR — Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness. The table is two-way, with both the number of transfer units and the heat capacity rate ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The thermal capacity ratios must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the thermal capacity ratio must be  $n$  elements long. The thermal capacity ratio is the fraction of minimum over maximum heat capacity rates.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Effectiveness table, E(NTU,CR) — Heat exchanger effectiveness at each breakpoint in lookup table over the number of transfer units and thermal capacity ratio**

unitless numerical array

Heat exchanger effectiveness at each breakpoint in its lookup table over the number of transfer units and thermal capacity ratio. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of number of transfer units and thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The effectiveness values must not be negative. They must align from top to bottom in order of increasing number of transfer units and from left to right in order of increasing thermal capacity ratio. The number of rows must equal the size of the **Number of heat transfer units vector** parameter, and the number of columns must equal the size of the **Thermal capacity ratio vector** parameter.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Wall thermal dynamics — Modeling assumption for transient response of wall to thermal changes**

Off (default) | On

Modeling assumption for the transient response of the wall to thermal changes. Set to `On` to impart a thermal mass to the wall and to capture the delay in its transient response to changes in temperature or heat flux. Such delays are relevant in thick walls, such as those required to sustain high pressures. The default setting assumes a wall thin enough for its transient response to be virtually instantaneous on the time scale of the heat transfer.

**Wall thermal mass — Heat required to raise wall temperature by one degree**

447 J/K (default) | scalar with units of energy over temperature

Heat required to raise wall temperature by one degree. Thermal mass is the product of mass with specific heat and a measure of the ability to absorb heat. A wall with thermal mass has a transient

response to sudden changes in surface temperature or heat flux. The larger the thermal mass, the slower that response, and the longer the time to steady state. The default value corresponds to a wall of stainless steel with a mass of approximately 1 kg.

**Dependencies**

This parameter applies solely to the **Wall thermal dynamics** setting of On.

**Wall thermal resistance — Resistance of the wall to heat flow by thermal conduction**

1.6e-4 K/W (default) | scalar with units of temperature over power

Resistance of the wall to heat flow by thermal conduction, and the inverse of thermal conductance, or the product of thermal conductivity with the ratio of surface area to length. Wall resistance adds to convective and fouling resistances to determine the overall heat transfer coefficient between the flows.

**Gas 1|2 Tab****Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Cross-sectional area of the flow channel at its narrowest point. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum of the areas in the collection—minus the occlusion due to walls, ridges, plates, or other barriers.

**Fluid volume — Total volume of fluid in the gas 1 or gas 2 flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of fluid contained in the gas 1 or gas 2 flow channel.

**Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point**

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

**Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones**

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones**

4000 (default) | unitless scalar



End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (G) block for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet — Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances — Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness — Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor — Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor — Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block interpolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Euler number vector – Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Heat transfer parameterization – Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area – Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Gas-wall heat transfer coefficient – Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer – Length of pipe or channel**

1 m (default) | scalar with units of length

Length of the pipe or channel from inlet to outlet.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.

### Reynolds number vector for Colburn factor — Values of the Reynolds number at which to specify the Colburn factor data

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block inter- and extrapolates the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Colburn factor vs. Reynolds number`.

### Colburn factor vector — Colburn factor at each breakpoint in lookup table over Reynolds number

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Colburn factor vs. Reynolds number`.

### Reynolds number vector for Nusselt number — Reynolds number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Prandtl number vector for Nusselt number — Prandtl number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Prandtl number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number table, Nu (Re,Pr) — Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Fouling factor — Measure of thermal resistance due to fouling deposits**

1.6e-4 K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

## Effects and Initial Conditions

### **Gas initial temperature — Temperature in the gas 1 or gas 2 channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the gas 1 or gas 2 channel at the start of simulation.

### **Gas 1|2 initial pressure — Pressure in the gas 1 or gas 2 channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the gas 1 or gas 2 channel at the start of simulation.

## Version History

**Introduced in R2017b**

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

E-NTU Heat Transfer | Heat Exchanger Interface (G) | Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (G)

## Heat Exchanger (G-TL)

Heat exchanger for systems with gas and thermal liquid flows

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (G-TL) block models the complementary cooling and heating of fluids held briefly in thermal contact across a thin conductive wall. The wall can store heat in its bounds, adding to the heat transfer a slight transient delay that scales in proportion to its thermal mass. The fluids are single phase—pure gas on one side, pure liquid on the other. Neither fluid can switch phase and so, as latent heat is never released, the exchange is strictly one of sensible heat.

Sensible heat exchangers abound in machinery. The fuel heaters that in some jets keep ice from precipitating in fuel lines and from choking fuel strainers work by blasting bleed air still hot from the compressor over the fuel lines. The oil coolers that in some motorcycles keep lubricating oil from overheating work likewise by rushing ram air at ambient temperature over the oil lines. The bleed and ram air are gas flows and the fuel and oil are thermal liquid flows.



### Block Variants

The heat transfer model depends on the choice of block variant. The block has two variants: E-NTU Model and Simple Model. Use the **Modeling option** parameter to change the variant.

#### E-NTU Model

The default variant. Its heat transfer model derives from the Effectiveness-NTU method. Heat transfer in the steady state then proceeds at a fraction of the ideal rate which the flows, if kept each at its inlet temperature, and if cleared of every thermal resistance in between, could in theory support:

$$Q_{\text{Act}} = \epsilon Q_{\text{Max}}$$



where  $Q_{\text{Act}}$  the actual heat transfer rate,  $Q_{\text{Max}}$  is the ideal heat transfer rate, and  $\varepsilon$  is the fraction of the ideal rate actually observed in a real heat exchanger encumbered with losses. The fraction is the heat exchanger effectiveness, and it is a function of the number of transfer units, or NTU, a measure of the ease with which heat moves between flows, relative to the ease with which the flows absorb that heat:

$$NTU = \frac{1}{RC_{\text{Min}}},$$

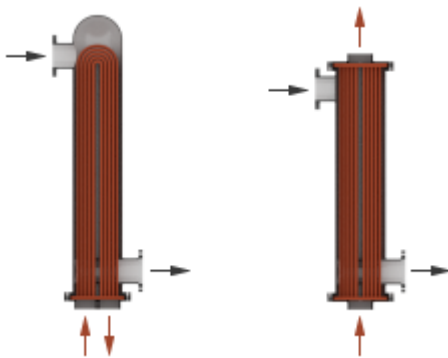
where the fraction is the overall thermal conductance between the flows and  $C_{\text{Min}}$  is the smallest of the heat capacity rates from among the flows—that belonging to the flow least capable of absorbing heat. The heat capacity rate of a flow depends on the specific heat of the fluid ( $c_p$ ) and on its mass flow rate through the exchanger ( $\dot{m}$ ):

$$C = c_p \dot{m}.$$

The effectiveness depends also on the relative disposition of the flows, the number of passes between them, and the mixing condition for each. This dependence reflects in the effectiveness expression used, with different flow arrangements corresponding to different expressions. For a list of the effectiveness expressions, see the E-NTU Heat Transfer block.

### Flow Arrangement

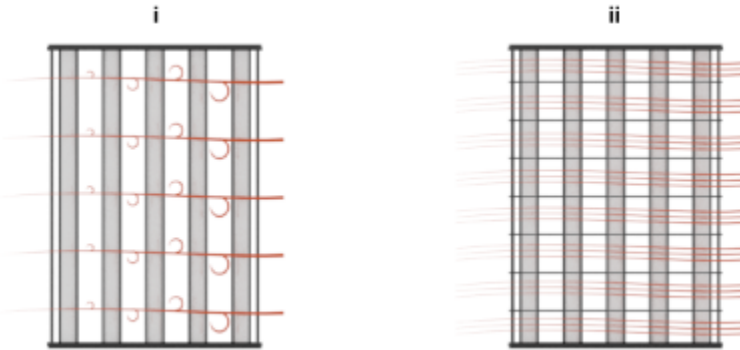
Use the **Flow arrangement** block parameter to set how the flows meet in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those same tubes. The figure shows an example. The tube flow can make one pass through the shell flow (shown right) or, for greater exchanger effectiveness, multiple passes (left).



Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger, are assumed to manifest in the tabulated data.

### Mixing Condition

Use the **Cross flow arrangement** parameter to mix each of the flows, one of the flows, or none of the flows. Mixing in this context is the lateral movement of fluid in channels that have no internal barriers, normally guides, baffles, fins, or walls. Such movement serves to even out temperature variations in the transverse plane. Mixed flows have variable temperature in the longitudinal plane alone. Unmixed flows have variable temperature in both the transverse and longitudinal planes. The figure shows a mixed flow (**i**) and an unmixed flow (**ii**).

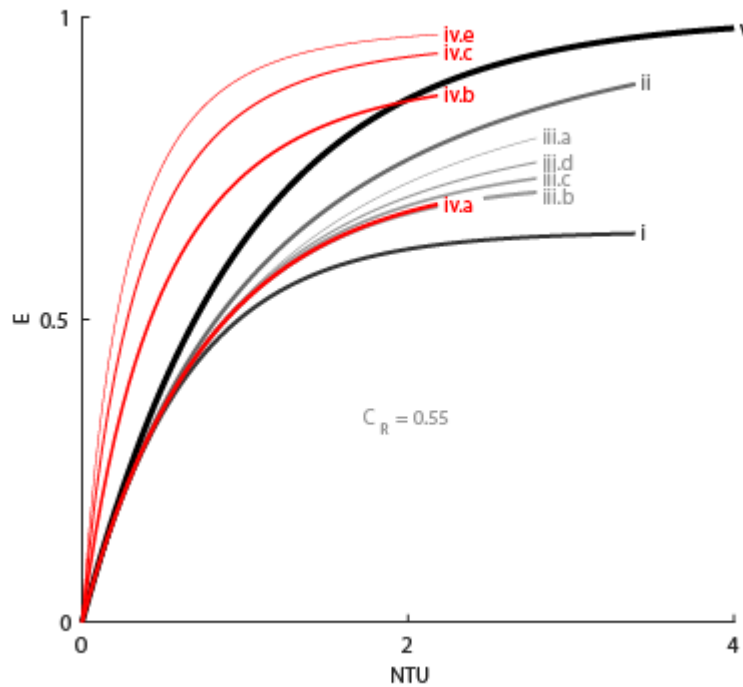


The distinction between mixed and unmixed flows is considered only in cross flow arrangements. There, longitudinal temperature variation in one fluid produces transverse temperature variation in the second fluid that mixing can even out. In counter and parallel flow arrangements, longitudinal temperature variation in one fluid produces longitudinal temperature variation in the second fluid and mixing, as it is of little effect here, is ignored.

#### Effectiveness Curves

Shell-and-tube exchangers with multiple passes (**iv.b-e** in the figure for 2, 3, and 4 passes) are most effective. Of exchangers with a single pass, those with counter flows (**ii**) are most effective and those with parallel flows (**i**) are least.

Cross-flow exchangers are intermediate in effectiveness, with mixing condition playing a factor. They are most effective when both flows are unmixed (**iii.a**) and least effective when both flows are mixed (**iii.b**). Mixing just the flow with the smallest heat capacity rate (**iii.c**) lowers the effectiveness more than mixing just the flow with the largest heat capacity rate (**iii.d**).

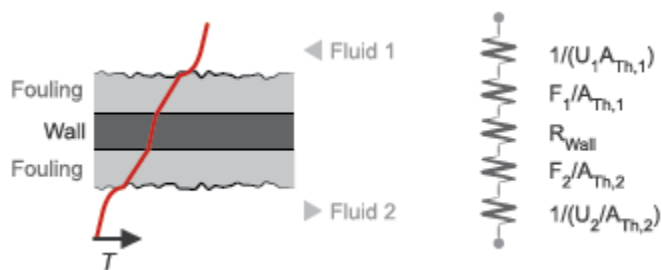


### Thermal Resistance

The overall thermal resistance,  $R$ , is the sum of the local resistances lining the heat transfer path. The local resistances arise from convection at the surfaces of the wall, conduction through the wall, and, if the wall sides are fouled, conduction through the layers of fouling. Expressed in order from gas side to thermal liquid side:

$$R = \frac{1}{U_G A_{Th,G}} + \frac{F_G}{A_{Th,G}} + R_W + \frac{F_{TL}}{A_{Th,TL}} + \frac{1}{U_{TL} A_{Th,TL}}$$

where  $U$  is the convective heat transfer coefficient,  $F$  is the fouling factor, and  $A_{Th}$  is the heat transfer surface area, each for the flow indicated in the subscript.  $R_W$  is the thermal resistance of the wall.



The wall thermal resistance and fouling factors are simple constants obtained from block parameters. The heat transfer coefficients are elaborate functions of fluid properties, flow geometry, and wall friction, and derive from standard empirical correlations between Reynolds, Nusselt, and Prandtl

numbers. The correlations depend on flow arrangement and mixing condition, and are detailed for each in the E-NTU Heat Transfer block on which the E-NTU Model variant is based.

### Thermal Mass

The wall is more than a thermal resistance for heat to pass through. It is also a thermal mass and, like the flows it divides, it can store heat in its bounds. The storage slows the transition between steady states so that a thermal perturbation on one side does not promptly manifest on the side across. The lag persists for the short time that it takes the heat flow rates from the two sides to balance each other. That time interval scales with the thermal mass of the wall:

$$C_{Q,W} = c_{p,W}M_W,$$

where  $c_{p,W}$  is the specific heat capacity and  $M_W$  the inertial mass of the wall. Their product gives the energy required to raise wall temperature by one degree. Use the **Wall thermal mass** block parameter to specify that product. The parameter is active when the **Wall thermal dynamics** setting is **On**.

Thermal mass is often negligible in low-pressure systems. Low pressure affords a thin wall with a transient response so fast that, on the time scale of the heat transfer, it is virtually instantaneous. The same is not true of high-pressure systems, common in the production of ammonia by the Haber process, where pressure can break 200 atmospheres. To withstand the high pressure, the wall is often thicker, and, as its thermal mass is heftier, so its transient response is slower.

Set the **Wall thermal dynamics** parameter to **Off** to ignore the transient lag, cut the differential variables that produce it, and, in reducing calculations, speed up the rate of simulation. Leave it **On** to capture the transient lag where it has a measurable effect. Experiment with the setting if necessary to determine whether to account for thermal mass. If simulation results differ to a considerable degree, and if simulation speed is not a factor, keep the setting **On**.

The wall, if modeled with thermal mass, is considered in halves. One half sits on the gas side and the other half sits on the thermal liquid side. The gas side is denoted side 1 and the thermal liquid side is denoted side 2. This notation is used in the calculations for heat transfer. The thermal mass divides evenly between the pair:

$$C_{Q,1} = C_{Q,2} = \frac{C_{Q,W}}{2}.$$

Energy is conserved in the wall. In the simple case of a wall half at steady state, heat gained from the fluid equals heat lost to the second half. The heat flows at the rate predicted by the E-NTU method for a wall without thermal mass. The rate is positive for heat flows directed from side 1 of the heat exchanger to side 2:

$$Q_1 = -Q_2 = \epsilon Q_{\text{Max}}.$$

In the transient state, the wall is in the course of storing or losing heat, and heat gained by one half no longer equals that lost to the second half. The difference in the heat flow rates varies over time in proportion to the rate at which the wall stores or loses heat. For side 1 of the heat exchanger:

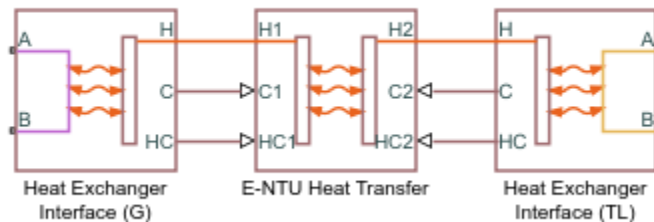
$$Q_1 = \epsilon Q_{\text{Max}} + C_{Q,1}\dot{T}_{W,1},$$

where  $\dot{T}_{W,1}$  is the rate of change in temperature in the wall half. Its product with the thermal mass of the wall half gives the rate at which heat accumulates there. That rate is positive when temperature

rises and negative when it drops. The closer the rate is to zero the closer the wall is to steady state. For side 2 of the heat exchanger:  $Q_2 = -\epsilon Q_{\text{Max}} + C_{Q,2} \dot{T}_{W,2}$ ,

### Composite Structure

The E-NTU Model variant is a composite component built from simpler blocks. A Heat Exchanger Interface (G) block models the gas flow, a Heat Exchanger Interface (TL) block models the thermal liquid flow, and an E-NTU Heat Transfer block models the heat exchanged across the wall between the flows. The figure shows the block connections for the E-NTU Model block variant.



### Simple Model

The alternative variant. Its heat transfer model depends on the concept of *specific dissipation*, a measure of the heat transfer rate observed when gas and thermal liquid inlet temperatures differ by one degree. Its product with the inlet temperature difference gives the expected heat transfer rate:

$$Q = \xi(T_{\text{In,G}} - T_{\text{In,TL}}),$$

where  $\xi$  is specific dissipation and  $T_{\text{In}}$  is inlet temperature for gas (subscript G) or thermal liquid (subscript TL). The specific dissipation is a tabulated function of the mass flow rates into the exchanger through the gas and thermal liquid inlets:

$$\xi = f(\dot{m}_{\text{In,G}}, \dot{m}_{\text{In,TL}}),$$

To accommodate reverse flows, the tabulated data can extend over positive and negative flow rates, in which case the inlets can also be thought of as outlets. The data normally derives from measurement of heat transfer rate against temperature in a real prototype:

$$\xi = \frac{Q}{T_{\text{In,G}} - T_{\text{In,TL}}}.$$

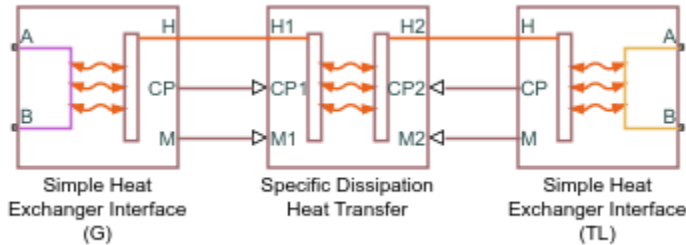
The heat transfer model, as it relies almost entirely on tabulated data, and as that data normally derives from experiment, requires little detail about the exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger modeled, are assumed to manifest entirely in the tabulated data.

See the Specific Dissipation Heat Transfer block for more detail on the heat transfer calculations.

### Composite Structure

The Simple Model variant is a composite component. A Simple Heat Exchanger Interface (G) block models the gas flow and a Simple Heat Exchanger Interface (TL) block models the thermal liquid flow. Mass, momentum, and energy conservation in the flow channels derive from the corresponding

interface blocks. A Specific Dissipation Heat Transfer block captures the heat exchanged across the wall between the flows.



## Ports

### Conserving

#### A1 – Gas port

gas

Opening for gas to enter and exit its side of the heat exchanger.

#### B1 – Gas port

gas

Opening for gas to enter and exit its side of the heat exchanger.

#### A2 – Thermal liquid port

thermal liquid

Opening for thermal liquid to enter and exit its side of the heat exchanger.

#### B2 – Thermal liquid port

thermal liquid

Opening for thermal liquid to enter and exit its side of the heat exchanger.

## Parameters

### Modeling option – Heat transfer model

E-NTU Model | Simple model

Set the heat transfer model for the block.

### Block Variant: Simple Model

#### Heat Transfer

#### Gas 1 mass flow rate vector, $\text{mdot1}$ – Mass flow rate of gas at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of gas at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of rows in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $m$  elements long.

**Thermal Liquid 2 mass flow rate vector, `mdot2` — Mass flow rate of thermal liquid at each breakpoint in lookup table for specific heat dissipation table**

numerical array with units of mass over time

Mass flow rate of thermal liquid at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

**Specific heat dissipation table, `SD(mdot1, mdot2)` — Specific heat dissipation at each breakpoint in lookup table over mass flow rates of gas and thermal liquid**

numerical array with units of power over temperature

Specific heat dissipation at each breakpoint in its lookup table over the mass flow rates of gas and thermal liquid. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of gas and thermal liquid mass flow rates. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The specific heat dissipation values must not be negative. They must align from top to bottom in order of increasing mass flow rate in the gas channel, and from left to right in order of increasing mass flow rate in the thermal liquid channel. The number of rows must equal the size of the **Gas 1 mass flow rate vector** parameter, and the number of columns must equal the size of the **Thermal liquid 2 mass flow rate vector** parameter.

**Check if violating maximum specific dissipation — Warning condition for specific heat dissipation in excess of minimum heat capacity rate**

Warning (default) | None

Warning condition for specific heat dissipation in excess of minimum heat capacity rate. Heat capacity rate is the product of mass flow rate and specific heat, and its minimum value is the lowest between the flows. This minimum gives the specific dissipation for a heat exchanger with maximum effectiveness and cannot be exceeded. See the Specific Dissipation Heat Transfer block for more detail.

**Gas 1**

**Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop**

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block uses linear interpolation and nearest extrapolation to obtain the pressure drop at any mass flow rate.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. The vector must have the same number of elements as the **Pressure drop vector** parameter and these elements must increase monotonically from left to right.

**Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate**

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block uses linear interpolation and nearest extrapolation to obtain the pressure drop at any mass flow rate.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. The vector must have the same number of elements as the **Mass flow rate vector** parameter and these elements must increase monotonically from left to right.

**Reference inflow temperature — Absolute inlet temperature assumed in tabulated data**

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Reference inflow pressure — Absolute inlet pressure assumed in tabulated data**

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Mass flow rate threshold for flow reversal — Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities. See the Simple Heat Exchanger Interface block (on which the Simple Model variant is based) for detail on the calculations.

**Gas 1 volume — Volume of fluid in the gas flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the gas flow channel.

**Cross-sectional area at ports A1 and B1 — Flow area at the inlet and outlet of the flow channel**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the gas flow channel. Ports in the same flow channel are of the same size.



**Thermal Liquid 2****Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop**

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block uses linear interpolation and nearest extrapolation to obtain the pressure drop at any mass flow rate.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. The vector must have the same number of elements as the **Pressure drop vector** parameter and these elements must increase monotonically from left to right.

**Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate**

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block uses linear interpolation and nearest extrapolation to obtain the pressure drop at any mass flow rate.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. The vector must have the same number of elements as the **Mass flow rate vector** parameter and these elements must increase monotonically from left to right.

**Reference inflow temperature — Absolute inlet temperature assumed in tabulated data**

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Reference inflow pressure — Absolute inlet pressure assumed in tabulated data**

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Threshold mass flow rate for flow reversal — Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities. See the Simple Heat Exchanger Interface block (on which the Simple Model variant is based) for detail on the calculations.

**Fluid volume — Volume of fluid in the thermal liquid flow channel**0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the thermal liquid flow channel.

**Cross-sectional area at ports A2 and B2 — Flow area at the inlet and outlet of the flow channel**0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the thermal liquid flow channel. Ports in the same flow channel are of the same size.

**Block Variant: E-NTU Model****Common Tab****Flow arrangement — Manner in which the flows align in the heat exchanger**

Parallel or counter flow (default) | Shell and tube | Cross flow | Generic - effectiveness table

Manner in which the flows align in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those tubes. Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger.

**Number of shell passes — Number of times the flow traverses the shell before exiting**

1 (default) | unitless scalar

Number of times the flow traverses the shell before exiting.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Cross flow type — Mixing condition in each of the flow channels**

Both fluids mixed (default) | Both fluids unmixed | Thermal Liquid 1 mixed &amp; Thermal Liquid 2 unmixed | Thermal Liquid 1 unmixed &amp; Thermal Liquid 2 mixed

Mixing condition in each of the flow channels. Mixing in this context is the lateral movement of fluid as it proceeds along its flow channel toward the outlet. The flows remain separate from each other. Unmixed flows are common in channels with plates, baffles, or fins. This setting reflects in the effectiveness of the heat exchanger, with unmixed flows being most effective and mixed flows being least.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Number of heat transfer units vector, NTU — Number of transfer units at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Number of transfer units at each breakpoint in the lookup table for the heat exchanger effectiveness number. The table is two-way, with both the number of transfer units and the thermal capacity ratio serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the effectiveness at any number of transfer units.

The numbers specified must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of rows in the **Effectiveness table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the number of transfer units must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Thermal capacity ratio vector, CR — Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness. The table is two-way, with both the number of transfer units and the heat capacity rate ratio serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the effectiveness at any thermal capacity ratio.

The thermal capacity ratios must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the thermal capacity ratio must be  $n$  elements long. The thermal capacity ratio is the fraction of minimum over maximum heat capacity rates.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Effectiveness table, E(NTU,CR) — Heat exchanger effectiveness at each breakpoint in lookup table over the number of transfer units and thermal capacity ratio**

unitless numerical array

Heat exchanger effectiveness at each breakpoint in its lookup table over the number of transfer units and thermal capacity ratio. The block uses linear interpolation and nearest extrapolation to obtain the effectiveness at any pair of number of transfer units and thermal capacity ratio.

The effectiveness values must be not be negative. They must align from top to bottom in order of increasing number of transfer units and from left to right in order of increasing thermal capacity ratio. The number of rows must equal the size of the **Number of heat transfer units vector** parameter, and the number of columns must equal the size of the **Thermal capacity ratio vector** parameter.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Wall thermal dynamics — Modeling assumption for transient response of wall to thermal changes**

Off (default) | On

Modeling assumption for the transient response of the wall to thermal changes. Set to On to impart a thermal mass to the wall and to capture the delay in its transient response to changes in temperature or heat flux. Such delays are relevant in thick walls, such as those required to sustain high pressures. The default setting assumes a wall thin enough for its transient response to be virtually instantaneous on the time scale of the heat transfer.

**Wall thermal mass — Heat required to raise wall temperature by one degree**

447 J/K (default) | scalar with units of energy over temperature

Heat required to raise wall temperature by one degree. Thermal mass is the product of mass with specific heat and a measure of the ability to absorb heat. A wall with thermal mass has a transient response to sudden changes in surface temperature or heat flux. The larger the thermal mass, the slower that response, and the longer the time to steady state. The default value corresponds to a wall of stainless steel with a mass of approximately 1 kg.

**Dependencies**

This parameter applies solely to the **Wall thermal dynamics** setting of On.

**Wall thermal resistance — Resistance of the wall to heat flow by thermal conduction**

1.6e-4 K/W (default) | scalar with units of temperature over power

Resistance of the wall to heat flow by thermal conduction. Wall resistance adds to convective and fouling resistances to determine the overall heat transfer coefficient between the flows.

**Gas 1****Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Total area of the flow cross section measured where the channel is its narrowest and the flow its fastest. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum over the collection (minus any occlusion due to walls, ridges, plates, and other barriers).

**Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point**

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

**Gas volume — Total volume of fluid contained in the flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of fluid contained in the gas flow channel.

**Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones**

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones**

4000 (default) | unitless scalar

End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (G) and Heat Exchanger Interface (TL) blocks for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet — Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances — Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness — Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor — Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor — Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block uses linear interpolation and nearest extrapolation to obtain the Darcy friction factor at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Darcy friction factor at any Reynolds number.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Euler number vector – Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Heat transfer parameterization – Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area – Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Fluid-wall heat transfer coefficient – Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer – Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length traversed in heat transfer between fluid and wall. This length factors in the calculation of the hydraulic diameter from which the heat transfer coefficient and the Reynolds number, as defined in the tabulated heat transfer parameterizations, derives.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.

**Reynolds number vector for Colburn factor – Values of the Reynolds number at which to specify the Colburn factor data**

unitless numerical array



Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block uses linear interpolation and nearest extrapolation to obtain the Colburn factor at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

#### Colburn factor vector – Colburn factor at each breakpoint in lookup table over Reynolds number

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

#### Reynolds number vector for Nusselt number – Reynolds number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### Prandtl number vector for Nusselt number – Prandtl number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any Prandtl number.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number

of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### **Nusselt number table, Nu (Re,Pr) — Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### **Fouling factor — Measure of thermal resistance due to fouling deposits**

$1.6e-4$  K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

#### **Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**

$100$  W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

#### **Thermal Liquid 2**

#### **Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point**

$0.01$  m<sup>2</sup> (default) | scalar with units of length squared

Total area of the flow cross section measured where the channel is its narrowest and the flow its fastest. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum over the collection (minus any occlusion due to walls, ridges, plates, and other barriers).

#### **Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point**

$0.1$  m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

**Liquid volume — Total volume of fluid contained in the flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of fluid contained in the thermal liquid flow channel.

**Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones**

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones**

4000 (default) | unitless scalar

End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (G) and Heat Exchanger Interface (TL) blocks for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet – Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances – Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness – Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor – Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor – Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block uses linear interpolation and nearest extrapolation to obtain the Darcy friction factor at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Darcy friction factor at any Reynolds number.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Euler number vector — Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Heat transfer parameterization — Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area — Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Fluid-wall heat transfer coefficient — Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer — Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length traversed in heat transfer between fluid and wall. This length factors in the calculation of the hydraulic diameter from which the heat transfer coefficient and the Reynolds number, as defined in the tabulated heat transfer parameterizations, derives.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.

#### Reynolds number vector for Colburn factor – Values of the Reynolds number at which to specify the Colburn factor data

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block uses linear interpolation and nearest extrapolation to obtain the Colburn factor at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

#### Colburn factor vector – Colburn factor at each breakpoint in lookup table over Reynolds number

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block uses linear interpolation and nearest extrapolation to obtain the Euler number at any Reynolds number.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

**Reynolds number vector for Nusselt number — Reynolds number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any Reynolds number.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Prandtl number vector for Nusselt number — Prandtl number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any Prandtl number.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number table, Nu (Re,Pr) — Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block uses linear interpolation and nearest extrapolation to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.



**Fouling factor — Measure of thermal resistance due to fouling deposits**

1.6e-4 K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

**Effects and Initial Conditions****Gas 1 initial temperature — Temperature in the gas channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the gas channel at the start of simulation

**Gas 1 initial pressure — Pressure in the gas channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the gas channel at the start of simulation.

**Thermal Liquid 2 dynamic compressibility — Option to model pressure dynamics in the thermal liquid channel**

On (default) | Off

Option to model the pressure dynamics in the thermal liquid channel. Setting this parameter to Off removes the pressure derivative terms from the component energy and mass conservation equations. The pressure inside the heat exchanger is then reduced to the weighted average of the two port pressures.

**Thermal Liquid 2 initial temperature — Temperature in the thermal liquid channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the thermal liquid channel at the start of simulation

**Thermal Liquid 2 initial pressure — Pressure in the thermal liquid channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the thermal liquid channel at the start of simulation.

**Version History**

Introduced in R2019a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

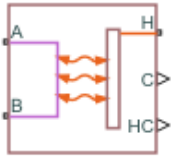
### **See Also**

E-NTU Heat Transfer | Heat Exchanger Interface (TL) | Heat Exchanger Interface (G) | Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (TL) | Simple Heat Exchanger Interface (G)

# Heat Exchanger Interface (G)

Gas side of heat exchanger

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



## Description

The Heat Exchanger Interface (G) block models thermal transfer by a gaseous flow within a heat exchanger. Use a second heat exchanger block to model the fluid pair. The interfaces can be in different fluid domains, such as one in liquid and one in gas. Use an E-NTU Heat Transfer block to couple the interfaces and capture the heat exchange between the fluids.

## Mass Balance

The fixed-volume construction of the block allows you to capture variations in fluid mass flow rates due to compressibility. The overall mass accumulation rate is equal to the sum of the mass flow rates through the ports:

$$\dot{M} = \dot{m}_A + \dot{m}_B,$$

where  $\dot{M}$  is the mass accumulation rate and  $\dot{m}$  is the mass flow rate. The subscripts denote ports **A** and **B**. The mass flow rate is positive when it is directed into the gas channel. Variations in density are reflected in the mass accumulation rate:

$$\dot{M} = \left[ \left( \frac{\partial \rho}{\partial p} \right)_u \frac{dp}{dt} + \left( \frac{\partial \rho}{\partial u} \right)_p \frac{du}{dt} \right] V,$$

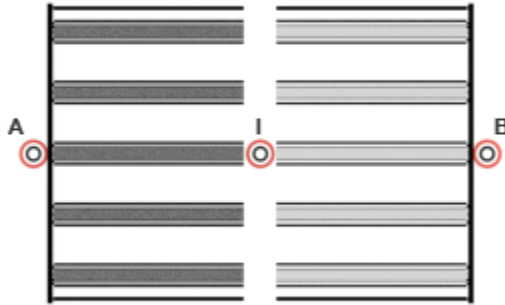
where:

- $\rho$  is density.
- $p$  is pressure.
- $u$  is specific internal energy.
- $V$  is volume.

## Momentum Balance

Balancing momentum between the inlet and outlet ports of the heat exchanger dictates the flow direction and speed within the exchanger. Changes in momentum are due primarily due to friction losses from pipe turns, which translate to changes in pressure. Local resistances, such as bends, elbows, and tees can result in flow separation that leads to minor additional pressure losses. For steady flows, the mass flow rate remains constant.

A momentum balance is applied to each segment of the gas (pipe) volume. This figure shows a tube bank divided into two volumes and three nodes. The nodes correspond to ports **A**, **B**, and the fluid volume, **I**. Fluid states, such as pressure and temperature, and fluid properties, such as density and viscosity, are defined at these nodes.



Note that flow inertia is negligible and the flow is considered to be quasi-steady state. The translation of transients to mass flow rates can be offset: due to coupling between density, pressure, and temperature, propagation of changes throughout the system is not instantaneous. Other sources and sinks of momentum, such as differences in head between ports or radial deformations of the channel wall, are not considered. The momentum balance for the half volume at port **A** is:

$$p_A - p_I = \Delta p_{f,A},$$

where  $p$  is the pressure at the node indicated in the subscript.  $\Delta p_{f,A}$  is the total pressure loss between the port node and the internal node due to friction. The total pressure loss includes both major and minor losses. For the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \Delta p_{f,B}.$$

### Friction

Pressure changes due to friction vary with the square of the mass flow rate for turbulent flows and with the magnitude of the mass flow rate for laminar flows. This pressure change is characterized by three dimensionless parameters: the Darcy friction factor, the pressure loss coefficient, and the Euler number. These numbers are calculated from empirical correlations or are estimated from lookup tables, depending on the **Pressure loss parameterization** parameter.

Classification of "laminar" or "turbulent" flow is based on the Reynolds number. When the Reynolds number is above the **Turbulent flow lower Reynolds number limit** parameter, the flow is fully turbulent. Below the **Laminar flow upper Reynolds number limit** parameter, the flow is fully laminar. Reynolds numbers in between these values indicate transitional flow. Transitional flows show characteristics of both laminar and turbulent flows. In the Simscape Fluids language, numerical blending is applied between these bounding values.

### Correlations for tubes

For tubes, the Darcy friction factor,  $f_D$ , is used. In the half volume at port **A**, the momentum balance is:

$$p_A - p_I = \frac{f_{D,A} \dot{m}_A |\dot{m}_A| (L + L_{Add})}{2\rho_A D_H A_{Min}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where  $L$  is the tube length and  $L_{Add}$  is the added tube length that would reproduce the minor viscous losses if used in place of elbows, tees, unions, or other local resistances.  $A$  is the tube cross-sectional area; in the event of a non-uniform cross-sectional area,  $A_{min}$  should be used.  $D_H$  is the tube hydraulic diameter, or the diameter of a circle equal in area to the tube cross section:

$$D_H = \sqrt{\frac{4A_{Min}}{\pi}}.$$

If the tube has a circular cross section, the hydraulic diameter and the tube diameter are the same.

For the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \frac{f_{D,B} \dot{m}_B |\dot{m}_B| (L + L_{Add})}{2\rho_B D_H A_{Min}^2} \left( \frac{L + L_{Add}}{2} \right).$$

For turbulent flows, the Darcy friction factor is calculated with the Haaland correlation. The Reynolds number is established at the bounding port:

$$f_D = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{Re} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2},$$

where  $\epsilon_R$  is wall roughness, taken as a characteristic height. This parameter is specified in the **Internal surface absolute roughness** parameter.

For laminar flows, the friction factor depends on the tube shape and is calculated with the tube shape factor:

$$f_D = \frac{\lambda}{Re},$$

where  $\lambda$  is the shape factor. The Reynolds number is calculated at the bounding port as:

$$Re = \frac{D_H \dot{m}}{\mu A_{Min}}.$$

Substituting  $Re$  into the pressure loss equation at port **A**, the momentum balance is reformulated as:

$$p_A - p_I = \frac{\lambda_A \mu_A \dot{m}_A}{2\rho_A D_H^2 A_{Min}} \left( \frac{L + L_{Add}}{2} \right),$$

Likewise, for the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \frac{\lambda_B \mu_B \dot{m}_B}{2\rho_B D_H^2 A_{Min}} \left( \frac{L + L_{Add}}{2} \right).$$

#### Using the constant loss coefficient

For channels other than tubes, use the pressure loss coefficient,  $\xi$ . For turbulent flows in the half volume at port **A**, the momentum balance is:

$$p_A - p_I = \frac{1}{2} \xi \frac{\dot{m}_A |\dot{m}_A|}{2\rho_A A_{\text{Min}}^2},$$

For turbulent flows in the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \frac{1}{2} \xi \frac{\dot{m}_B |\dot{m}_B|}{2\rho_B A_{\text{Min}}^2},$$

For laminar flows in the half volume at port **A**, the momentum balance is:

$$p_A - p_I = \frac{1}{2} \xi \text{Re}_L \frac{\dot{m}_A \mu_A}{2D_H \rho_A A_{\text{Min}}},$$

where  $\text{Re}_L$  is the **Laminar flow upper Reynolds number limit** block parameter. For laminar flows in the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \frac{1}{2} \xi \text{Re}_L \frac{\dot{m}_B \mu_B}{2D_H \rho_B A_{\text{Min}}}$$

#### Using Tabulated data - Darcy friction factor vs. Reynolds number

You can use tabulated data to determine the Darcy friction factor based on the Reynolds number for tube flows. For the half volume at port **A**, the momentum balance is:

$$p_A - p_I = \frac{f_{D,A} \dot{m}_A |\dot{m}_A|}{2\rho_A D_H A_{\text{Min}}^2} \left( \frac{L + L_{\text{Add}}}{2} \right).$$

For the half volume at port **B**, the momentum balance is:

$$p_B - p_I = \frac{f_{D,B} \dot{m}_B |\dot{m}_B|}{2\rho_B D_H A_{\text{Min}}^2} \left( \frac{L + L_{\text{Add}}}{2} \right).$$

For the turbulent regime, the friction factor is determined from a tabulated function of the Reynolds number:

$$f_D = f_D(\text{Re}).$$

The breakpoints of the tabulated function derive from the vector block parameters. The **Reynolds number vector for Darcy friction factor** parameter specifies the independent variable and the **Darcy friction factor vector** parameter specifies the dependent variable. Linear interpolation is applied between breakpoints. Outside of the tabulated data range, the nearest breakpoint determines the friction factor.

In the laminar regime, the friction factor is calculated from the shape factor,  $\lambda$ :

$$f_D = \frac{\lambda}{\text{Re}}.$$

#### Using Tabulated data - Euler number vs. Reynolds number

You can use tabulated data to determine the Euler number based on the Reynolds number. This calculation is dependent on flow regime, and the Euler number is formulated as a tabulated function of the Reynolds number:

$$Eu = Eu(Re).$$

The breakpoints in Tabulated data - Euler number vs. Reynolds number are specified by Reynolds number and Euler number vectors. The **Reynolds number vector for Euler number** parameter specifies the independent variables, the Reynolds numbers, and the **Euler number vector** parameter specifies the dependent variable, the Euler number, at each Reynolds number. Linear interpolation is used to determine values between breakpoints. Outside of the tabulated data range, the value at the nearest breakpoint is used.

For turbulent flows, the momentum balance for the half volume at port **A** is:

$$p_A - p_I = Eu_A \frac{\dot{m}_A |\dot{m}_A|}{\rho_A A_{Min}^2},$$

where  $Eu$  is the Euler number at port **A**. For turbulent flows, the momentum balance for the half volume at port **B** is:

$$p_B - p_I = Eu_B \frac{\dot{m}_B |\dot{m}_B|}{\rho_B A_{Min}^2}.$$

For laminar flow in the half volume at port **A**, the momentum balance is:

$$p_A - p_I = Eu_L Re_L \frac{\dot{m}_A \mu_A}{4D_H \rho_A A_{Min}},$$

where  $Re_L$  is the **Laminar flow upper Reynolds number limit** parameter and  $Eu_L$  is the Euler number evaluated from tabulated data at that Reynolds number. For laminar flow in the half volume at port **B**, the momentum balance is:

$$p_B - p_I = Eu_L Re_L \frac{\dot{m}_B \mu_B}{4D_H \rho_B A_{Min}},$$

## Energy Balance

The energy balance within the gas volume is the sum of its flow rates across channel boundaries and the associated heat transfer. Energy can be transferred by advection at the ports and by convection at the wall. While conduction contributes to the energy balance at the ports, it is often negligible in comparison to advection. However, conduction is non-negligible in near-stationary fluids, such as when fluids are stagnant or changing direction. The energy balance equation is:

$$\dot{E}_{2P} = \phi_A + \phi_B + Q,$$

where:

- $\frac{\partial U}{\partial p}$  is the partial derivative of the internal energy of the gas volume with respect to pressure at constant temperature and volume.
- $p_I$  is the pressure of the gas volume.
- $\frac{\partial U}{\partial T}$  is the partial derivative of the internal energy of the gas volume with respect to temperature at constant pressure and volume.
- $T_I$  is the temperature of the gas volume.

- $\Phi_A$  and  $\Phi_B$  are energy flow rates at ports **A** and **B**, respectively.
- $Q$  is the heat transfer rate.

Advection and conduction are accounted for in  $\Phi$ , and convection is accounted for in  $Q$ . The heat transfer rate is positive when directed into the gas volume.

### Heat Transfer Rate

Heat transfer between the two heat exchanger fluids occurs in multiple ways: through convection at the fluid interfaces, conduction through layers of built-up fouling, and conduction through the thickness of the wall.

Heat transfer extends beyond the gas channel and therefore requires other blocks to model the entire heat exchanger system. A second heat exchanger interface block models the second flow channel while an E-NTU Heat Transfer block models the heat flow across the wall. Heat transfer parameters that are specific to the gas channel, but required by the E-NTU Heat Transfer block, are available through the physical signal ports:

- Port **C** outputs the heat capacity rate, which is a measure of the gas' ability to absorb heat and is required for calculating the number of heat transfer units (NTU). The heat capacity rate is calculated as:

$$C_R = c_p \dot{m},$$

where  $C_R$  is the heat capacity rate and  $c_p$  is the specific heat.

- Port **HC** outputs the heat transfer coefficient,  $U$ .

If the heat transfer coefficient is treated as a constant, its value is uniform across the flow channel. If the heat transfer coefficient is variable, it is calculated at each port from the expression:

$$U = \frac{Nu k}{D_{H,Q}},$$

where  $Nu$  is Nusselt number,  $k$  is thermal conductivity, and  $D_{H,Q}$  is a hydraulic diameter for heat transfer. The hydraulic diameter  $D_{H,Q}$  is calculated as:

$$D_{H,Q} = \frac{4A_{Min}L_Q}{S_Q},$$

where  $S_Q$  is the **Heat transfer surface area** parameter and  $L_Q$  is the **Length of flow path for heat transfer** parameter.

The lower bound of the mean heat transfer coefficient is the **Minimum gas-wall heat transfer coefficient** parameter.

### Nusselt Number

The Nusselt number is derived from empirical correlations with the Reynolds and Prandtl numbers. Use the **Heat transfer parametrization** parameter to select the most appropriate formulation for your simulation.

The simplest parameterization, Constant heat transfer coefficient, obtains the heat transfer coefficient directly from the value of the **Gas-wall heat transfer coefficient** parameter.



**Correlations for tubes** uses analytical expressions with constant or calculated parameters to capture Nusselt number dependence on the flow regime for tube flows.

The remaining parameterizations are tabulated functions of the Reynolds number. These are useful for varying Nusselt numbers, or heat transfer coefficients, across flow regimes. The functions are generated from experimental data relating the Reynolds number to the Colburn factor or the Reynolds and Prandtl numbers to the Nusselt number.

#### **Constant heat transfer coefficient**

Using **Constant heat transfer coefficient**, specified in the **Gas-wall heat transfer coefficient** parameter, sets the heat transfer coefficient as a constant, and does not use the Nusselt number in calculations. Use this parameterization as a simple approximation for gas flows confined to the laminar regime.

#### **Correlation for tubes**

The Nusselt number depends on flow regime when using **Correlation for tubes**. For turbulent flows, its value changes in proportion to the Reynolds number and is calculated from the Gnielinski correlation:

$$\text{Nu} = \frac{\frac{f}{8}(\text{Re} - 1000)\text{Pr}}{1 + 12.7\sqrt{\frac{f}{8}(\text{Pr}^{2/3} - 1)}}$$

where Re is the Reynolds number, Nu is the Nusselt number, and Pr is the Prandtl number. The friction factor,  $f$ , is the same as the factor used in tube pressure loss calculations. For laminar flows, the Nusselt number is a constant. Its value is obtained from the **Nusselt number for laminar flow heat transfer** parameter,  $\text{Nu}_L$ :

$$\text{Nu} = \text{Nu}_L.$$

#### **Using Tabulated data - Colburn factor vs. Reynolds number**

You can use tabulated data to determine the Colburn factor based on the Reynolds number. The Colburn equation is used to determine the Nusselt number, which varies in proportion to the Reynolds number. The Colburn  $j$ -factor is a measure of proportionality between the Reynolds, Prandtl, and Nusselt numbers:

$$\text{Nu} = j(\text{Re}_Q)\text{Re}_Q\text{Pr}^{1/3}.$$

$\text{Re}_Q$  is the Reynolds number based on the hydraulic diameter for heat transfer,  $D_{H,Q}$ , and from the minimum free-flow area of the channel,  $A_{\text{Min}}$ :

$$\text{Re}_Q = \frac{\dot{m}D_{H,Q}}{A_{\text{Min}}\mu}$$

#### **Using Tabulated data - Nusselt number vs. Reynolds number & Prandtl number**

You can use a tabulated function to determine the Nusselt number from the Prandtl and Reynolds numbers. Linear interpolation is used to determine values between breakpoints. The Nusselt number is a function of both Re and Pr, and therefore the **Reynolds number vector for Nusselt number**, **Prandtl number vector for Nusselt number**, and **Nusselt number table, Nu(Re,Pr)** parameters define the table breakpoints:

$$\text{Nu} = \text{Nu}(\text{Re}_Q, \text{Pr}).$$

The tabulated Reynolds number must be calculated using the hydraulic diameter for heat transfer,  $D_{H,Q}$ .

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables” and “Initial Conditions for Blocks with Finite Gas Volume”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Ports

#### Conserving

##### **A — Gas port**

gas

Entry or exit point on the gas side of the heat exchanger.

##### **B — Gas port**

gas

Entry or exit point on the gas side of the heat exchanger.

##### **H — Thermal boundary**

thermal

Thermal boundary between the modeled fluid and the heat exchanger interface.

#### Input

##### **C — Heat capacity rate**

physical signal

Instantaneous value of the heat capacity rate for the gas flow, specified as a physical signal.

##### **HC — Heat transfer coefficient**

physical signal

Instantaneous value of the heat transfer coefficient between gas flow and the wall, specified as a physical signal.

### Parameters

##### **Minimum free-flow area — Cross-sectional area of flow channel at its narrowest point**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Cross-sectional area of the flow channel at its narrowest point. If the channel is a collection of ducts, tubes, slots, or grooves, this area is the sum of the areas in the collection, minus the blockage due to walls, ridges, plates, or other barriers.

### Hydraulic diameter — Diameter or equivalent diameter of a circular channel

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow. If the diameter of the cross-section varies, the value of this parameter is the diameter at its narrowest point. For non-circular channels, the hydraulic diameter is the equivalent diameter of a circle with the same area of the existing channel.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube that has a circular cross section, the hydraulic diameter is equal to the true diameter.

### Gas volume — Total volume of fluid contained in flow channel

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of the fluid contained in the gas or thermal liquid flow channel.

### Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent regimes

2000 (default) | scalar

Start of the transition from the laminar regime to the turbulent regime. Above this number, inertial forces become increasingly dominant. The default value is given for circular pipes and tubes with smooth surfaces.

### Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent regimes

4000 (default) | scalar

End of the transition from the laminar regime to the turbulent regime. Below this number, viscous forces become increasingly dominant. The default value is for circular pipes and tubes with smooth surfaces.

### Pressure loss parameterization — Mathematical model for pressure loss due to friction

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss due to friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (TL) blocks for the calculations by parameterization.

### Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports

0.1 (default) | scalar

Aggregate loss coefficient for all flow resistances in the flow channel, including wall friction (major losses) and local resistances due to bends, elbows, and other geometry changes (minor losses).

The loss coefficient is an empirical, dimensionless number used to express the pressure losses due to friction. It can be calculated from experimental data or obtained from product data sheets.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Constant loss coefficient.

**Length of flow path from inlet to outlet – Distance traveled from port to port**

1 m (default) | scalar with units of length

Total distance the flow must travel between the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels where the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to friction at the wall.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes or Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances – Aggregate minor pressure loss expressed in length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss, expressed as a length. The length of a straight channel results in equivalent losses to the sum of existing local resistances from elbows, tees, and unions. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

**Internal surface absolute roughness – Mean height of wall surface variations that contribute to frictional losses**

15e-6 m (default) | scalar with units of length

Mean height of the wall surface variations that contribute to frictional losses. The greater the mean height, the rougher the wall and the larger the pressure loss due to friction. Surface roughness is required to derive the Darcy friction factor from the Haaland correlation.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

**Laminar friction constant for Darcy friction factor – Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | scalar

Pressure loss correction for laminar flow. This parameter is referred to as the shape factor, and can be used to derive the Darcy friction factor for pressure loss calculations in the laminar regime. The default value is for cylindrical pipes and tubes.

Some additional shape factors for non-circular cross-sections can be determined from analytical solutions to the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with an aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96. A slender conduit between parallel plates also has a shape factor of 96.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

### **Reynolds number vector for Darcy friction factor – Reynolds number at each breakpoint in Darcy friction factor lookup table**

numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block interpolates between and extrapolates from the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is handled by the MATLAB® linear estimator and extrapolation is handled by the nearest function.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent regimes. The number of values in this vector must be equal to the size of the **Darcy friction factor vector** parameter to calculate tabulated breakpoints.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

### **Darcy friction factor vector – Darcy friction factor at each breakpoint in Reynolds number lookup table**

numerical array

Darcy friction factor at each breakpoint in the lookup table of Reynolds numbers. The block interpolates between and extrapolates from the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is handled by the MATLAB linear estimator and extrapolation is handled by the nearest function.

The Darcy friction factor must not be negative and must align from left to right in order of increasing Reynolds number. The number of values in this vector must be equal to the size of the **Reynolds number vector for Darcy friction factor** parameter to calculate tabulated breakpoints.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

### **Reynolds number vector for Euler number – Reynolds number at each breakpoint in the Euler number lookup table**

numerical array

Reynolds number at each breakpoint in the Euler number lookup table. The block interpolates between and extrapolates from the breakpoints to obtain the Reynolds number at any Euler number. Interpolation is handled by the MATLAB linear estimator and extrapolation is handled by the nearest function.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent regimes. The number of values in this vector must be equal to the size of the **Euler number vector** parameter to calculate tabulated breakpoints.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Euler number vs. Reynolds number.

**Euler number vector — Euler number at each breakpoint in the Reynolds number lookup table**

numerical array

Euler number at each breakpoint in the Reynolds number lookup table. The block interpolates between and extrapolates from the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is handled by the MATLAB `linear` estimator and extrapolation is handled by the `nearest` function.

The Euler number must not be negative and must align from left to right in order of increasing Reynolds number. The number of values in this vector must be equal to the size of the **Reynolds number vector for Euler number** parameter to calculate tabulated breakpoints.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Euler number vs. Reynolds number.

**Heat transfer parameterization — Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number &amp; Prandtl number

Mathematical model for heat transfer between the fluid and the wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculations. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Gas-wall heat transfer coefficient — Heat transfer coefficient for convection between fluid and wall**100 W/(m<sup>2</sup> \* K) (default) | scalar

Heat transfer coefficient for convection between the fluid and the wall.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Constant heat transfer coefficient.

**Heat transfer surface area — Effective surface area used in heat transfer between fluid and wall**0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between the fluid and the wall. The effective surface area is the sum of primary and secondary surface areas, the area where the wall is exposed to fluid and the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Length of flow path for heat transfer — Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length for heat transfer between fluid and wall. This length is used to determine the channel hydraulic diameter.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive scalar

Constant value of the Nusselt number for laminar flows. The Nusselt number is required to calculate the heat transfer coefficient between the fluid and the wall. The default value is for cylindrical pipes and tubes.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Correlations for tubes.

**Reynolds number vector for Colburn factor – Reynolds number at each breakpoint in Colburn factor lookup table**

numerical array

Reynolds number at each breakpoint in the Colburn factor lookup table. The block interpolates between and extrapolates from the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is handled by the MATLAB `linear` estimator and extrapolation is handled by the `nearest` function.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent regimes. The number of values in this vector must be equal to the size of the **Colburn factor vector** parameter to calculate tabulated breakpoints.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number.

**Colburn factor vector – Colburn factor at each breakpoint in Reynolds number lookup table**

numerical array

The Colburn factor at each breakpoint in the Reynolds number lookup table. The block interpolates between and extrapolates from the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is handled by the MATLAB `linear` estimator and extrapolation is handled by the `nearest` function.

The Colburn factor must be zero or positive and align from left to right in order of increasing Reynolds number. The number of values in this vector must be equal to the size of the **Reynolds number vector for Colburn factor** parameter to calculate tabulated breakpoints.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number.

**Reynolds number vector for Nusselt number — Reynolds number at each breakpoint in Nusselt number lookup table**

numerical array

The Reynolds number at each breakpoint in the Nusselt number lookup table. Either the Reynolds number or the Prandtl number can serve as an independent variable. The block interpolates between and extrapolates from the breakpoints to obtain the Nusselt number at any Reynolds number. Interpolation is handled by the MATLAB `linear` estimator and extrapolation is handled by the `nearest` function.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent regimes. The size of the vector must equal the number of rows in the **Nusselt number table,  $Nu(\text{Re}, \text{Pr})$**  parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Prandtl number vector for Nusselt number — Prandtl number at each breakpoint in the Nusselt number lookup table**

numerical array

Prandtl number at each breakpoint in the Nusselt number lookup table. Either the Prandtl number or the Reynolds number can serve as an independent variable. The block interpolates between and extrapolates from the breakpoints to obtain the Nusselt number at any Prandtl number. Interpolation is handled by the MATLAB `linear` estimator and extrapolation is handled by the `nearest` function.

The Prandtl number must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent regimes. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Nusselt number table,  $Nu(\text{Re}, \text{Pr})$  — Nusselt number at each breakpoint in Reynolds-Prandtl number lookup table**

numerical array

The Nusselt number at each breakpoint in the Reynolds-Prandtl number lookup table. The block interpolates between and extrapolates from the breakpoints to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. The Nusselt number is required to calculate the heat transfer coefficient.

The Nusselt number must be greater than zero. Each value must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl number. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.



### Dependencies

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

### Threshold mass flow rate for flow reversal — Upper bound of numerically smooth region for mass flow rate

1e-4 kg/s (default) | scalar with units of mass per unit time

The mass flow rate below which numerical smoothing is applied. This is employed to avoid discontinuity during flow stagnation. See the Simple Heat Exchanger Interface (G) block for more information about these calculations.

## Version History

Introduced in R2019a

### Extended Capabilities

#### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

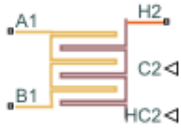
### See Also

E-NTU Heat Transfer | Heat Exchanger Interface (TL)

## Heat Exchanger (TL)

Heat exchanger for systems with thermal liquid and controlled flows

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (TL) block models the cooling and heating of fluids through conduction over a thin wall. The properties of a single-phase thermal liquid are defined on the **Thermal Liquid** tab. The second fluid is a controlled fluid, which is specified only by the user-defined parameters on the **Controlled Fluid** tab. It does not receive any properties from the domain fluid network. The heat exchange between the fluids is based on the thermal liquid sensible heat.



### Block Variants

Two heat transfer models are available:

- The E-NTU Model
- The Simple Model

To set one of these models, use the **Modeling option** parameter.

#### The E-NTU Model Variant

The E-NTU model, based on the Effectiveness-NTU method, is the block default variant. Steady-state heat transfer is determined based on a coefficient relating ideal to real losses in the system:

$$Q_{\text{Act}} = \epsilon Q_{\text{Max}}$$

where

- $Q_{\text{Act}}$  the actual heat transfer rate.

- $Q_{\text{Max}}$  is the ideal heat transfer rate.
- $\varepsilon$  is the heat exchanger effectiveness, which is based on the ratio of heat capacity rates,  $\frac{C_{\text{Min}}}{C_{\text{Max}}}$ , and the exchanger Number of Transfer Units:

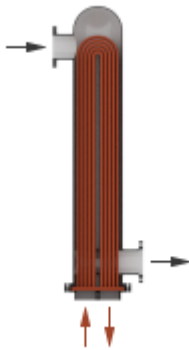
$$NTU = \frac{1}{RC_{\text{Min}}},$$

where  $R$  is the overall thermal resistance, which is discussed in “Thermal Resistance” on page 1-1031 below.  $C_{\text{Min}}$  is the lesser heat capacity rate of the two fluids and  $C_{\text{Max}}$  is the greater heat capacity rate of the two fluids. The heat capacity rate is calculated as  $C = c_p \dot{m}$ .

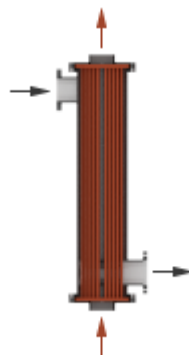
Additionally, the exchanger effectiveness depends on the number of passes between the fluids and the fluid mixing conditions. For different parameterizations of  $\varepsilon$ , see E-NTU Heat Transfer. Connect an E-NTU Heat Transfer block to a Heat Exchanger (TL) block to specify the heat transfer properties in with the E-NTU method.

### Flow Arrangement

Use the **Flow arrangement** parameter to define the flow configuration in terms of pipe orientation or effectiveness tables. When using the shell-and-tube configuration, you can select the number of passes in the exchanger. A multi-pass exchanger resembles the image below.



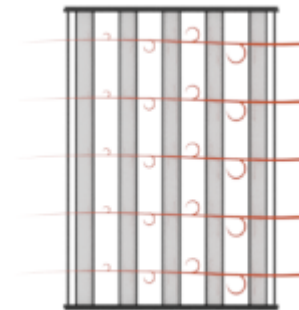
A single-pass exchanger resembles the image below.



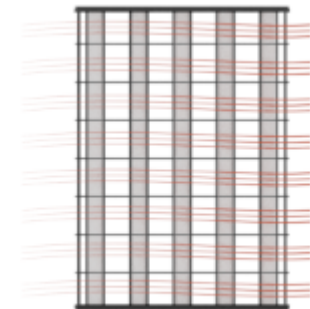
Other flow arrangements are possible through a generic parameterization by tabulated effectiveness data. This table does not require specific heat exchanger configuration details, such as flow arrangement, mixing, and passes, for modeling the heat transfer between the fluids.

### Mixing Condition

Use the **Cross flow type** parameter to model flows that are not restricted by baffles or walls, which homogenizes fluid temperature along the direction of flow of the second fluid and varies perpendicular to the second fluid flow. Unmixed flows vary in temperature both along and perpendicular to the flow direction of the second fluid. An example of a heat exchanger with one mixed and one unmixed fluid resembles the configuration below.



A heat exchanger with two unmixed fluids resembles the configuration below.

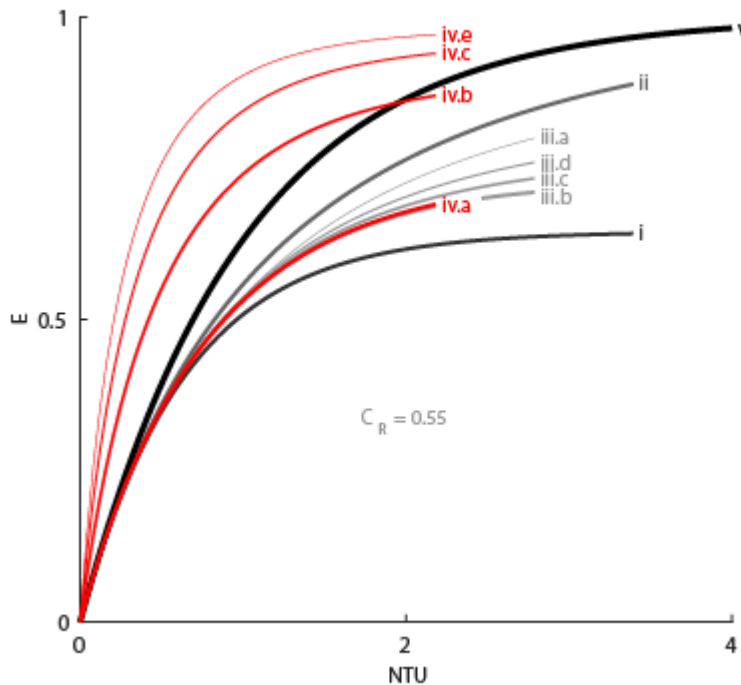


In counter and parallel flow arrangements, longitudinal temperature variation in one fluid results in a longitudinal change in temperature variation in the second fluid and mixing is not taken into account.

### Effectiveness Curves

Shell-and-tube exchangers with multiple passes (**iv.b-e** in the figure for 2, 3, and 4 passes) are the most effective type of heat exchanger. For single-pass heat exchangers, the counter-flow configuration (**ii**) is the most effective, and parallel flow (**i**) is the least.

Cross-flow exchangers are intermediate in effectiveness, with mixing condition playing a factor. They are most effective when both flows are unmixed (**iii.a**) and least effective when both flows are mixed (**iii.b**). Mixing just the flow with the smallest heat capacity rate (**iii.c**) lowers the effectiveness more than mixing just the flow with the largest heat capacity rate (**iii.d**).



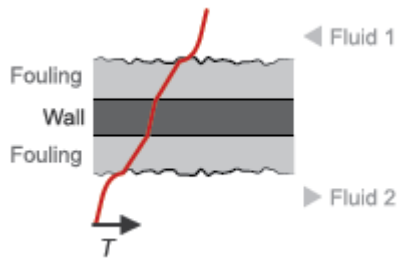
### Thermal Resistance

The overall thermal resistance,  $R$ , is the sum of the local resistances to heat transfer due to convection, conduction, and fouling along the heat exchanger walls:

$$R = \frac{1}{U_{Th}A_{Th}} + \frac{F_{Th}}{A_{Th}} + R_W + \frac{F_C}{A_C} + \frac{1}{U_C A_C},$$

where:

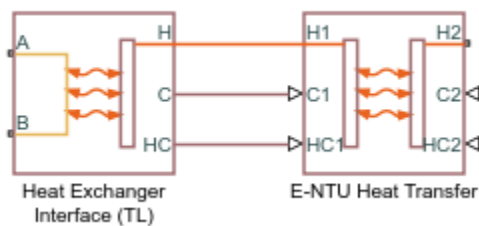
- $U_{Th}$  is the heat transfer coefficient between the thermal liquid and the wall.
- $U_C$  is the heat transfer coefficient between the controlled fluid and the wall, which is received as a physical signal at port **HC2**.
- $F_{Th}$  is the thermal liquid **Fouling factor**.
- $F_C$  is the controlled fluid **Fouling factor**.
- $A_{Th}$  is the thermal liquid **Heat transfer surface area**.
- $A_C$  is the controlled fluid **Heat transfer surface area**.
- $R_W$  is the **Wall thermal resistance**.



The heat transfer coefficients depend on the heat exchanger configuration and fluid properties. See the E-NTU Heat Transfer reference page for more information.

### Composite Structure

When the Heat Exchanger (TL) block employs the E-NTU Model variant, it is a composite of the Heat Exchanger Interface (TL) and E-NTU Heat Transfer blocks:



### The Simple Model Variant

Heat transfer by the simple model is based on specific dissipation:

$$Q = \xi(T_{In,Th} - T_{In,C}),$$

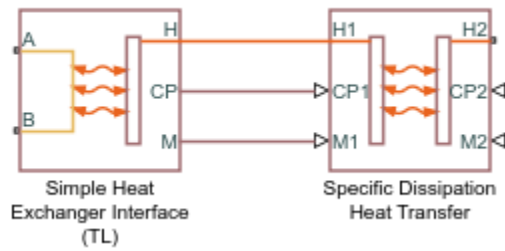
where:

- $\xi$  is specific dissipation, which is a function of the mass flow rates of the thermal and controlled liquids.
- $T_{In,Th}$  is the thermal liquid inlet temperature.
- $T_{In,C}$  is the controlled liquid inlet temperature.

The simple model is based on linear interpolation of user-provided tabulated data and does not capture individual features of the heat exchanger.

### Composite Structure

When the Heat Exchanger (TL) block employs the Simple Model variant, it is a composite of the Simple Heat Exchanger Interface (TL) and Specific Dissipation Heat Transfer blocks:



## Ports

### Conserving

#### A1 – Thermal liquid port

thermal liquid

Opening for thermal liquid to enter and exit its side of the heat exchanger.

#### B1 – Thermal liquid port

thermal liquid

Opening for thermal liquid to enter and exit its side of the heat exchanger.

### Input

#### C – Heat capacity rate

physical signal

Instantaneous value of the heat capacity rate for the controlled flow.

#### Dependencies

This port is active only for the block variant of E-NTU Model.

#### HC – Heat transfer coefficient

physical signal

Instantaneous value of the heat transfer coefficient between the controlled flow and the wall.

#### Dependencies

This port is active only for the block variant of E-NTU Model.

#### CP2 – Isobaric specific heat of controlled fluid

physical signal

Instantaneous value of the isobaric specific heat for the controlled fluid.

#### Dependencies

This port is active only for the block variant of Simple Model.

#### M2 – Mass flow rate of controlled fluid

physical signal

Instantaneous value of the mass flow rate of the controlled fluid.

#### Dependencies

This port is active only for the block variant of Simple Model.

## Parameters

### Modeling option — Heat transfer model

E-NTU Model | Simple model

Set the heat transfer model for the block.

### Block Variant: Simple Model

#### Heat Transfer Tab

### Thermal liquid mass flow rate vector — Mass flow rate of thermal liquid at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of thermal liquid at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

### Controlled fluid mass flow rate vector — Mass flow rate of controlled fluid at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of controlled fluid at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

### Specific heat dissipation table — Specific heat dissipation at each breakpoint in lookup table over mass flow rates of thermal liquid and controlled fluid

numerical array with units of power over temperature

Specific heat dissipation at each breakpoint in its lookup table over the mass flow rates of thermal liquid and controlled fluid. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of thermal liquid and controlled fluid mass flow rates. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The specific heat dissipation values must not be negative. They must align from top to bottom in order of increasing mass flow rate in the thermal liquid channel, and from left to right in order of increasing mass flow rate in the controlled fluid channel. The number of rows must equal the size of



the **Thermal liquid mass flow rate vector** parameter, and the number of columns must equal the size of the **Controlled fluid mass flow rate vector** parameter.

### Check if violating maximum specific dissipation — Warning condition for specific heat dissipation in excess of minimum heat capacity rate

Warning (default) | None

Warning condition for specific heat dissipation in excess of minimum heat capacity rate. Heat capacity rate is the product of mass flow rate and specific heat, and its minimum value is the lowest between the flows. This minimum gives the specific dissipation for a heat exchanger with maximum effectiveness and cannot be exceeded. See the Specific Dissipation Heat Transfer block for more detail.

### Pressure Loss Tab

#### Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Pressure drop vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Mass flow rate vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Reference inflow temperature — Absolute inlet temperature assumed in tabulated data

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

#### Reference inflow pressure — Absolute inlet pressure assumed in tabulated data

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated

data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Mass flow rate threshold for flow reversal – Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities known to produce simulation errors at zero flow. See the Simple Heat Exchanger Interface (TL) block (on which the Simple Model variant is based) for detail on the calculations for the thermal liquid side of the exchanger.

**Thermal liquid volume – Volume of fluid in the thermal liquid flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the thermal liquid flow channel.

**Cross-sectional area at ports A1 and B1 – Flow area at the inlet and outlet of the flow channel**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the thermal liquid flow channel. The ports are of the same size.

**Block Variant: E-NTU Model**

**Common Tab**

**Flow arrangement – Manner in which the flows align in the heat exchanger**

Parallel or counter flow (default) | Shell and tube | Cross flow | Generic - effectiveness table

Manner in which the flows align in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those tubes. Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger.

**Number of shell passes – Number of times the flow traverses the shell before exiting**

1 (default) | unitless scalar

Number of times the flow traverses the shell before exiting.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Cross flow type – Mixing condition in each of the flow channels**

Both fluids mixed (default) | Both fluids unmixed | Thermal liquid mixed & Controlled Fluid unmixed | Thermal liquid unmixed & Controlled Fluid mixed

Mixing condition in each of the flow channels. Mixing in this context is the lateral movement of fluid as it proceeds along its flow channel toward the outlet. The flows remain separate from each other. Unmixed flows are common in channels with plates, baffles, or fins. This setting reflects in the effectiveness of the heat exchanger, with unmixed flows being most effective and mixed flows being least.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Number of heat transfer units vector, NTU – Number of transfer units at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Number of transfer units at each breakpoint in the lookup table for the heat exchanger effectiveness number. The table is two-way, with both the number of transfer units and the thermal capacity ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any number of transfer units. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The numbers specified must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of rows in the **Effectiveness table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the number of transfer units must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Thermal capacity ratio vector, CR – Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness. The table is two-way, with both the number of transfer units and the heat capacity rate ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The thermal capacity ratios must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the thermal capacity ratio must be  $n$  elements long. The thermal capacity ratio is the fraction of minimum over maximum heat capacity rates.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Effectiveness table, E(NTU,CR) – Heat exchanger effectiveness at each breakpoint in lookup table over the number of transfer units and thermal capacity ratio**

unitless numerical array

Heat exchanger effectiveness at each breakpoint in its lookup table over the number of transfer units and thermal capacity ratio. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of number of transfer units and thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The effectiveness values must be not be negative. They must align from top to bottom in order of increasing number of transfer units and from left to right in order of increasing thermal capacity ratio. The number of rows must equal the size of the **Number of heat transfer units vector**

parameter, and the number of columns must equal the size of the **Thermal capacity ratio vector** parameter.

#### **Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

#### **Wall thermal resistance — Resistance of the wall to heat flow by thermal conduction**

1.6e-4 K/W (default) | scalar with units of temperature over power

Resistance of the wall to heat flow by thermal conduction, and the inverse of thermal conductance, or the product of thermal conductivity with the ratio of surface area to length. Wall resistance adds to convective and fouling resistances to determine the overall heat transfer coefficient between the flows.

#### **Thermal liquid Tab**

#### **Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Cross-sectional area of the flow channel at its narrowest point. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum of the areas in the collection—minus the occlusion due to walls, ridges, plates, or other barriers.

#### **Thermal liquid volume — Total volume of fluid in the thermal liquid flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of fluid contained in the thermal liquid flow channel.

#### **Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point**

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

#### **Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones**

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

#### **Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones**

4000 (default) | unitless scalar

End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (TL) block for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet — Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances — Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness — Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor — Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor — Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block interpolates and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Euler number vector – Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Euler number vs. Reynolds number.

**Heat transfer parameterization — Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area — Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Thermal liquid-wall heat transfer coefficient — Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer — Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length traversed in heat transfer between fluid and wall. This length factors in the calculation of the hydraulic diameter from which the heat transfer coefficient and the Reynolds number, as defined in the tabulated heat transfer parameterizations, derives.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer — Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.



### Reynolds number vector for Colburn factor — Values of the Reynolds number at which to specify the Colburn factor data

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block inter- and extrapolates the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Colburn factor vs. Reynolds number`.

### Colburn factor vector — Colburn factor at each breakpoint in lookup table over Reynolds number

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Colburn factor vs. Reynolds number`.

### Reynolds number vector for Nusselt number — Reynolds number at each breakpoint in lookup table for Nusselt number

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

#### Dependencies

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Prandtl number vector for Nusselt number — Prandtl number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Prandtl number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Nusselt number table, Nu (Re,Pr) — Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

**Fouling factor — Measure of thermal resistance due to fouling deposits**

1.6e-4 K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

**Controlled Fluid Tab****Heat transfer surface area — Aggregate heat transfer surface area on the controlled fluid side**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Aggregate heat transfer surface area on the controlled fluid side

**Fouling factor — Measure of thermal resistance due to fouling deposits**

1e-4 K/W (default) | scalar with units of length squared times temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the controlled fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**

100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between the controlled fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

**Effects and Initial Conditions****Thermal liquid initial temperature — Temperature in the thermal liquid channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the thermal liquid channel at the start of simulation.

**Thermal liquid initial pressure — Pressure in the thermal liquid channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the thermal liquid channel at the start of simulation.

**Version History**

Introduced in R2016a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

E-NTU Heat Transfer | Heat Exchanger Interface (TL) | Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (TL)

## Heat Exchanger (TL-TL)

Heat exchanger for systems with two thermal liquid flows

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (TL-TL) block models the complementary cooling and heating of fluids held briefly in thermal contact across a thin conductive wall. The wall can store heat in its bounds, adding to the heat transfer a slight transient delay that scales in proportion to its thermal mass. The fluids are single phase—each a thermal liquid. Neither fluid can switch phase and so, as latent heat is never released, the exchange is strictly one of sensible heat.



### Block Variants

The heat transfer model depends on the choice of block variant. The block has two variants: E-NTU Model and Simple Model. Use the **Modeling option** parameter to change the variant.

#### E-NTU Model

The default variant. Its heat transfer model derives from the Effectiveness-NTU method. Heat transfer in the steady state then proceeds at a fraction of the ideal rate which the flows, if kept each at its inlet temperature, and if cleared of every thermal resistance in between, could in theory support:

$$Q_{\text{Act}} = \epsilon Q_{\text{Max}}$$

where  $Q_{\text{Act}}$  the actual heat transfer rate,  $Q_{\text{Max}}$  is the ideal heat transfer rate, and  $\epsilon$  is the fraction of the ideal rate actually observed in a real heat exchanger encumbered with losses. The fraction is the heat exchanger effectiveness, and it is a function of the number of transfer units, or NTU, a measure of the ease with which heat moves between flows, relative to the ease with which the flows absorb that heat:

$$NTU = \frac{1}{RC_{\text{Min}}},$$

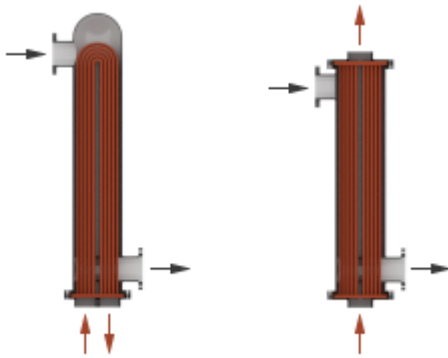
where the fraction is the overall thermal conductance between the flows and  $C_{\text{Min}}$  is the smallest of the heat capacity rates from among the flows—that belonging to the flow least capable of absorbing heat. The heat capacity rate of a flow depends on the specific heat of the fluid ( $c_p$ ) and on its mass flow rate through the exchanger ( $\dot{m}$ ):

$$C = c_p \dot{m}.$$

The effectiveness depends also on the relative disposition of the flows, the number of passes between them, and the mixing condition for each. This dependence reflects in the effectiveness expression used, with different flow arrangements corresponding to different expressions. For a list of the effectiveness expressions, see the E-NTU Heat Transfer block.

### Flow Arrangement

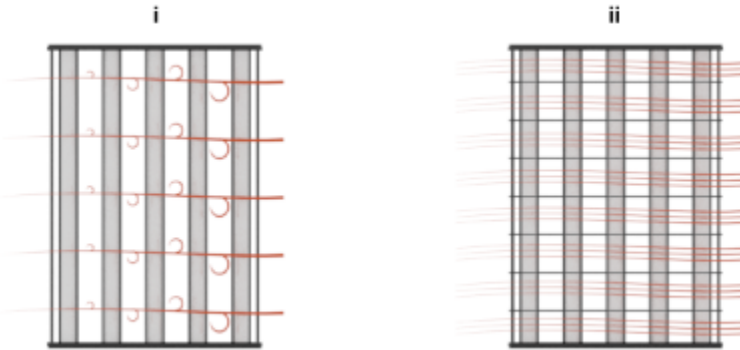
Use the **Flow arrangement** parameter to set how the flows meet in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those same tubes. The figure shows an example. The tube flow can make one pass through the shell flow (shown right) or, for greater exchanger effectiveness, multiple passes (left).



Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger, are assumed to manifest in the tabulated data.

### Mixing Condition

Use the **Cross flow type** parameter to mix each of the flows, one of the flows, or none of the flows. Mixing in this context is the lateral movement of fluid in channels that have no internal barriers, normally guides, baffles, fins, or walls. Such movement serves to even out temperature variations in the transverse plane. Mixed flows have variable temperature in the longitudinal plane alone. Unmixed flows have variable temperature in both the transverse and longitudinal planes. The figure shows a mixed flow (**i**) and an unmixed flow (**ii**).

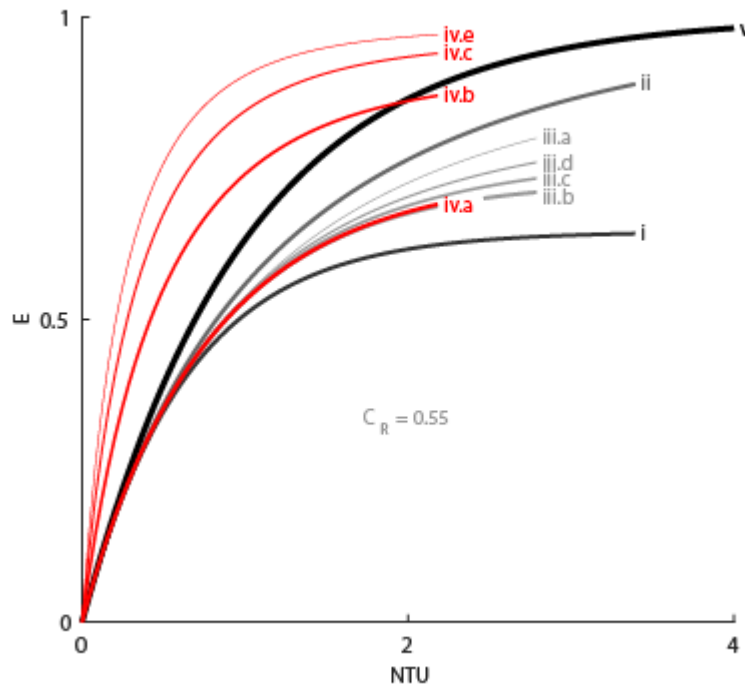


The distinction between mixed and unmixed flows is considered only in cross flow arrangements. There, longitudinal temperature variation in one fluid produces transverse temperature variation in the second fluid that mixing can even out. In counter and parallel flow arrangements, longitudinal temperature variation in one fluid produces longitudinal temperature variation in the second fluid and mixing, as it is of little effect here, is ignored.

#### Effectiveness Curves

Shell-and-tube exchangers with multiple passes (**iv.b-e** in the figure for 2, 3, and 4 passes) are most effective. Of exchangers with a single pass, those with counter flows (**ii**) are most effective and those with parallel flows (**i**) are least.

Cross-flow exchangers are intermediate in effectiveness, with mixing condition playing a factor. They are most effective when both flows are unmixed (**iii.a**) and least effective when both flows are mixed (**iii.b**). Mixing just the flow with the smallest heat capacity rate (**iii.c**) lowers the effectiveness more than mixing just the flow with the largest heat capacity rate (**iii.d**).

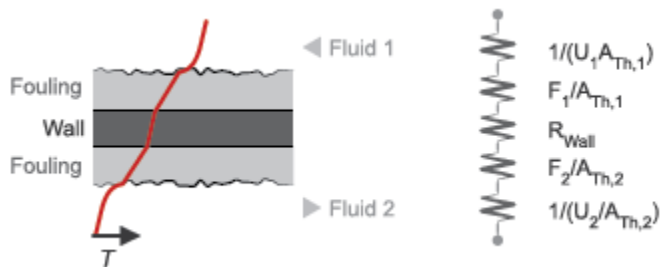


### Thermal Resistance

The overall thermal resistance,  $R$ , is the sum of the local resistances lining the heat transfer path. The local resistances arise from convection at the surfaces of the wall, conduction through the wall, and, if the wall sides are fouled, conduction through the layers of fouling. Expressed in order from thermal liquid side 1 to thermal liquid side 2:

$$R = \frac{1}{U_1 A_{Th,1}} + \frac{F_1}{A_{Th,1}} + R_{Wall} + \frac{F_2}{A_{Th,2}} + \frac{1}{U_2 A_{Th,2}},$$

where  $U$  is the convective heat transfer coefficient,  $F$  is the fouling factor, and  $A_{Th}$  is the heat transfer surface area, each for the flow indicated in the subscript.  $R_{Wall}$  is the thermal resistance of the wall.



The wall thermal resistance and fouling factors are simple constants obtained from block parameters. The heat transfer coefficients are elaborate functions of fluid properties, flow geometry, and wall friction, and derive from standard empirical correlations between Reynolds, Nusselt, and Prandtl

numbers. The correlations depend on flow arrangement and mixing condition, and are detailed for each in the E-NTU Heat Transfer block on which the E-NTU Model variant is based.

### Thermal Mass

The wall is more than a thermal resistance for heat to pass through. It is also a thermal mass and, like the flows it divides, it can store heat in its bounds. The storage slows the transition between steady states so that a thermal perturbation on one side does not promptly manifest on the side across. The lag persists for the short time that it takes the heat flow rates from the two sides to balance each other. That time interval scales with the thermal mass of the wall:

$$C_{Q,W} = c_{p,W}M_W,$$

where  $c_{p,W}$  is the specific heat capacity and  $M_W$  the inertial mass of the wall. Their product gives the energy required to raise wall temperature by one degree. Use the **Wall thermal mass** parameter to specify that product. The parameter is active when the **Wall thermal dynamics** setting is **On**.

Thermal mass is often negligible in low-pressure systems. Low pressure affords a thin wall with a transient response so fast that, on the time scale of the heat transfer, it is virtually instantaneous. The same is not true of high-pressure systems, common in the production of ammonia by the Haber process, where pressure can break 200 atmospheres. To withstand the high pressure, the wall is often thicker, and, as its thermal mass is heftier, so its transient response is slower.

Set the **Wall thermal dynamics** parameter to **Off** to ignore the transient lag, cut the differential variables that produce it, and, in reducing calculations, speed up the rate of simulation. Leave it **On** to capture the transient lag where it has a measurable effect. Experiment with the setting if necessary to determine whether to account for thermal mass. If simulation results differ to a considerable degree, and if simulation speed is not a factor, keep the setting **On**.

The wall, if modeled with thermal mass, is considered in halves. One half sits on thermal liquid side 1 and the other half sits on thermal liquid side 2. The thermal mass divides evenly between the pair:

$$C_{Q,1} = C_{Q,2} = \frac{C_{Q,W}}{2}.$$

Energy is conserved in the wall. In the simple case of a wall half at steady state, heat gained from the fluid equals heat lost to the second half. The heat flows at the rate predicted by the E-NTU method for a wall without thermal mass. The rate is positive for heat flows directed from side 1 of the heat exchanger to side 2:

$$Q_1 = -Q_2 = \epsilon Q_{\text{Max}}.$$

In the transient state, the wall is in the course of storing or losing heat, and heat gained by one half no longer equals that lost to the second half. The difference in the heat flow rates varies over time in proportion to the rate at which the wall stores or loses heat. For side 1 of the heat exchanger:

$$Q_1 = \epsilon Q_{\text{Max}} + C_{Q,1}\dot{T}_{W,1},$$

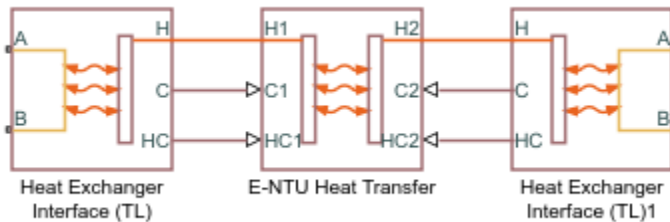
where  $\dot{T}_{W,1}$  is the rate of change in temperature in the wall half. Its product with the thermal mass of the wall half gives the rate at which heat accumulates there. That rate is positive when temperature rises and negative when it drops. The closer the rate is to zero the closer the wall is to steady state.

For side 2 of the heat exchanger:  $Q_2 = -\epsilon Q_{\text{Max}} + C_{Q,2}\dot{T}_{W,2}$ ,



### Composite Structure

The E-NTU Model variant is a composite component built from simpler blocks. A Heat Exchanger Interface (TL) block models the thermal liquid flow on side 1 of the heat exchanger. Another models the thermal liquid flow on side 2. An E-NTU Heat Transfer block models the heat exchanged across the wall between the flows. The figure shows the block connections for the E-NTU Model block variant.



### Simple Model

The alternative variant. Its heat transfer model depends on the concept of *specific dissipation*, a measure of the heat transfer rate observed when thermal liquid 1 and thermal liquid 2 inlet temperatures differ by one degree. Its product with the inlet temperature difference gives the expected heat transfer rate:

$$Q = \xi(T_{In,1} - T_{In,2}),$$

where  $\xi$  is specific dissipation and  $T_{in}$  is inlet temperature for thermal liquid 1 (subscript 1) or thermal liquid 2 (subscript 2). The specific dissipation is a tabulated function of the mass flow rates into the exchanger through the thermal liquid 1 and thermal liquid 2 inlets:

$$\xi = f(\dot{m}_1, \dot{m}_2)$$

To accommodate reverse flows, the tabulated data can extend over positive and negative flow rates, in which case the inlets can also be thought of as outlets. The data normally derives from measurement of heat transfer rate against temperature in a real prototype:

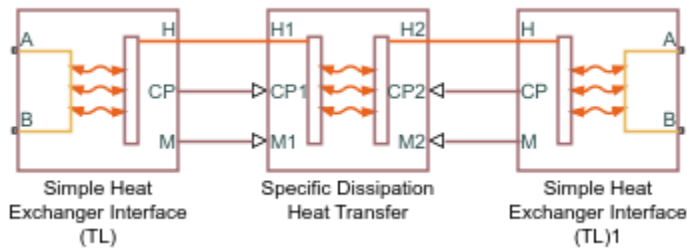
$$\xi = \frac{Q}{T_{In,1} - T_{In,2}}$$

The heat transfer model, as it relies almost entirely on tabulated data, and as that data normally derives from experiment, requires little detail about the exchanger. Flow arrangement, mixing condition, and number of shell or tube passes, if relevant to the heat exchanger modeled, are assumed to manifest entirely in the tabulated data.

See the Specific Dissipation Heat Transfer block for more detail on the heat transfer calculations.

### Composite Structure

The Simple Model variant is a composite component. A Simple Heat Exchanger Interface (TL) block models the thermal liquid flow on side 1 of the heat exchanger. Another models the thermal liquid flow on side 2. A Specific Dissipation Heat Transfer block captures the heat exchanged across the wall between the flows.



## Ports

### Conserving

#### A1 – Thermal liquid 1 port

thermal liquid

Opening for thermal liquid 1 to enter and exit its side of the heat exchanger.

#### B1 – Thermal liquid 1 port

thermal liquid

Opening for thermal liquid 1 to enter and exit its side of the heat exchanger.

#### A2 – Thermal liquid 2 port

thermal liquid

Opening for thermal liquid 2 to enter and exit its side of the heat exchanger.

#### B2 – Thermal liquid 2 port

thermal liquid

Opening for thermal liquid 2 to enter and exit its side of the heat exchanger.

## Parameters

### Modeling option – Heat transfer model

E-NTU Model | Simple model

Set the heat transfer model for the block.

### Block Variant: Simple Model

#### Heat Transfer Tab

#### Thermal Liquid 1 mass flow rate vector – Mass flow rate of thermal liquid 1 at each breakpoint in lookup table for specific heat dissipation table

numerical array with units of mass over time

Mass flow rate of thermal liquid 1 at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB linear type and extrapolation is nearest.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

**Thermal Liquid 2 mass flow rate vector — Mass flow rate of thermal liquid 2 at each breakpoint in lookup table for specific heat dissipation table**

numerical array with units of mass over time

Mass flow rate of thermal liquid 2 at each breakpoint in the lookup table for the specific heat dissipation table. The block inter- and extrapolates the breakpoints to obtain the specific heat dissipation of the heat exchanger at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative, but they must increase monotonically from left to right. Their number must equal the number of columns in the **Specific heat dissipation table** parameter. If the table has  $m$  rows and  $n$  columns, the mass flow rate vector must be  $n$  elements long.

**Specific heat dissipation table — Specific heat dissipation at each breakpoint in lookup table over mass flow rates of thermal liquid 1 and thermal liquid 2**

numerical array with units of power over temperature

Specific heat dissipation at each breakpoint in its lookup table over the mass flow rates of thermal liquid 1 and thermal liquid 2. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of thermal liquid 1 and thermal liquid 2 mass flow rates. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The specific heat dissipation values must be not be negative. They must align from top to bottom in order of increasing mass flow rate in the thermal liquid 1 channel, and from left to right in order of increasing mass flow rate in the thermal liquid 2 channel. The number of rows must equal the size of the **Thermal liquid 1 mass flow rate vector** parameter, and the number of columns must equal the size of the **Thermal liquid 2 mass flow rate vector** parameter.

**Check if violating maximum specific dissipation — Warning condition for specific heat dissipation in excess of minimum heat capacity rate**

Warning (default) | None

Warning condition for specific heat dissipation in excess of minimum heat capacity rate. Heat capacity rate is the product of mass flow rate and specific heat, and its minimum value is the lowest between the flows. This minimum gives the specific dissipation for a heat exchanger with maximum effectiveness and cannot be exceeded. See the Specific Dissipation Heat Transfer block for more detail.

**Thermal Liquid 1|2 Tab**

**Mass flow rate vector — Mass flow rate at each breakpoint in lookup table for pressure drop**

numerical array with units of mass per unit time

Mass flow rate at each breakpoint in the lookup table for the pressure drop. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The mass flow rates can be positive, zero, or negative and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number

must equal the size of the **Pressure drop vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Pressure drop vector — Pressure drop at each breakpoint in lookup table over mass flow rate**

numerical array with units of pressure

Pressure drop at each breakpoint in its lookup table over the mass flow rate. The block inter- and extrapolates the breakpoints to obtain the pressure drop at any mass flow rate. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The pressure drops can be positive, zero, or negative, and they can span across laminar, transient, and turbulent zones. They must, however, increase monotonically from left to right. Their number must equal the size of the **Mass flow rate vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Reference inflow temperature — Absolute inlet temperature assumed in tabulated data**

293.15 K (default) | scalar with units of temperature

Absolute temperature established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Reference inflow pressure — Absolute inlet pressure assumed in tabulated data**

0.101325 MPa (default) | scalar with units of pressure

Absolute pressure established at the inlet in the gathering of the tabulated pressure drops. The reference inflow temperature and pressure determine the fluid density assumed in the tabulated data. During simulation, the ratio of reference to actual fluid densities multiplies the tabulated pressure drop to obtain the actual pressure drop.

**Threshold mass flow rate for flow reversal — Upper bound of numerically smooth region for mass flow rate**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which its value is numerically smoothed to avoid discontinuities known to produce simulation errors at zero flow. See the Simple Heat Exchanger Interface (TL) block (on which the Simple Model variant is based) for detail on the calculations.

**Fluid volume — Volume of fluid in the thermal liquid 1 or thermal liquid 2 flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length cubed

Volume of fluid in the thermal liquid 1 or thermal liquid 2 flow channel.

**Cross-sectional area at ports A and B — Flow area at the inlet and outlet of the flow channel**

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Flow area at the inlet and outlet of the thermal liquid 1 or thermal liquid 2 flow channel. Ports in the same flow channel are of the same size.

**Block Variant: E-NTU Model****Common Tab****Flow arrangement — Manner in which the flows align in the heat exchanger**

Parallel or counter flow (default) | Shell and tube | Cross flow | Generic - effectiveness table

Manner in which the flows align in the heat exchanger. The flows can run parallel to each other, counter to each other, or across each other. They can also run in a pressurized shell, one through tubes enclosed in the shell, the other around those tubes. Other flow arrangements are possible through a generic parameterization based on tabulated effectiveness data and requiring little detail about the heat exchanger.

**Number of shell passes — Number of times the flow traverses the shell before exiting**

1 (default) | unitless scalar

Number of times the flow traverses the shell before exiting.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Cross flow type — Mixing condition in each of the flow channels**

Both fluids mixed (default) | Both fluids unmixed | Thermal Liquid 1 mixed & Thermal Liquid 2 unmixed | Thermal Liquid 1 unmixed & Thermal Liquid 2 mixed

Mixing condition in each of the flow channels. Mixing in this context is the lateral movement of fluid as it proceeds along its flow channel toward the outlet. The flows remain separate from each other. Unmixed flows are common in channels with plates, baffles, or fins. This setting reflects in the effectiveness of the heat exchanger, with unmixed flows being most effective and mixed flows being least.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Shell and tube.

**Number of heat transfer units vector, NTU — Number of transfer units at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Number of transfer units at each breakpoint in the lookup table for the heat exchanger effectiveness number. The table is two-way, with both the number of transfer units and the thermal capacity ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any number of transfer units. Interpolation is the MATLAB linear type and extrapolation is nearest.

The numbers specified must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of rows in the **Effectiveness table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the number of transfer units must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of Generic - effectiveness table.

**Thermal capacity ratio vector, CR — Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness**

unitless numerical array

Thermal capacity ratio at each breakpoint in lookup table for heat exchanger effectiveness. The table is two-way, with both the number of transfer units and the heat capacity rate ratio serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The thermal capacity ratios must be greater than zero and increase monotonically from left to right. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the vector for the thermal capacity ratio must be  $n$  elements long. The thermal capacity ratio is the fraction of minimum over maximum heat capacity rates.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Effectiveness table, E(NTU,CR) — Heat exchanger effectiveness at each breakpoint in lookup table over the number of transfer units and thermal capacity ratio**

unitless numerical array

Heat exchanger effectiveness at each breakpoint in its lookup table over the number of transfer units and thermal capacity ratio. The block inter- and extrapolates the breakpoints to obtain the effectiveness at any pair of number of transfer units and thermal capacity ratio. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The effectiveness values must not be negative. They must align from top to bottom in order of increasing number of transfer units and from left to right in order of increasing thermal capacity ratio. The number of rows must equal the size of the **Number of heat transfer units vector** parameter, and the number of columns must equal the size of the **Thermal capacity ratio vector** parameter.

**Dependencies**

This parameter applies solely to the **Flow arrangement** setting of `Generic - effectiveness table`.

**Wall thermal dynamics — Modeling assumption for transient response of wall to thermal changes**

Off (default) | On

Modeling assumption for the transient response of the wall to thermal changes. Set to `On` to impart a thermal mass to the wall and to capture the delay in its transient response to changes in temperature or heat flux. Such delays are relevant in thick walls, such as those required to sustain high pressures. The default setting assumes a wall thin enough for its transient response to be virtually instantaneous on the time scale of the heat transfer.

**Wall thermal mass — Heat required to raise wall temperature by one degree**

447 J/K (default) | scalar with units of energy over temperature

Heat required to raise wall temperature by one degree. Thermal mass is the product of mass with specific heat and a measure of the ability to absorb heat. A wall with thermal mass has a transient

response to sudden changes in surface temperature or heat flux. The larger the thermal mass, the slower that response, and the longer the time to steady state. The default value corresponds to a wall of stainless steel with a mass of approximately 1 kg.

### Dependencies

This parameter applies solely to the **Wall thermal dynamics** setting of On.

### Wall thermal resistance — Resistance of the wall to heat flow by thermal conduction

1.6e-4 K/W (default) | scalar with units of temperature over power

Resistance of the wall to heat flow by thermal conduction, and the inverse of thermal conductance, or the product of thermal conductivity with the ratio of surface area to length. Wall resistance adds to convective and fouling resistances to determine the overall heat transfer coefficient between the flows.

### Thermal Liquid 1|2 Tab

### Minimum free-flow area — Cross-sectional area of the flow channel at its narrowest point

0.01 m<sup>2</sup> (default) | scalar with units of length squared

Cross-sectional area of the flow channel at its narrowest point. If the channel is a collection of ducts, tubes, slots, or grooves, the area is the sum of the areas in the collection—minus the occlusion due to walls, ridges, plates, or other barriers.

### Fluid volume — Total volume of fluid in the thermal liquid 1 or thermal liquid 2 flow channel

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of fluid contained in the thermal liquid 1 or thermal liquid 2 flow channel.

### Hydraulic diameter for pressure loss — Effective diameter of the flow channel at its narrowest point

0.1 m (default) | scalar with units of length

Effective inner diameter of the flow at its narrowest point. For channels not circular in cross section, that diameter is of an imaginary circle equal in area to the flow cross section. Its value is the ratio of the minimum free-flow area to a fourth of its gross perimeter.

If the channel is a collection of ducts, tubes, slots, or grooves, the gross perimeter is the sum of the perimeters in the collection. If the channel is a single pipe or tube and it is circular in cross section, the hydraulic diameter is the same as the true diameter.

### Laminar flow upper Reynolds number limit — Start of transition between laminar and turbulent zones

2000 (default) | unitless scalar

Start of transition between laminar and turbulent zones. Above this number, inertial forces take hold and the flow grows progressively turbulent. The default value is characteristic of circular pipes and tubes with smooth surfaces.

### Turbulent flow lower Reynolds number limit — End of transition between laminar and turbulent zones

4000 (default) | unitless scalar

End of transition between laminar and turbulent zones. Below this number, viscous forces take hold and the flow grows progressively laminar. The default value is characteristic of circular pipes and tubes with smooth surfaces.

**Pressure loss parameterization — Mathematical model for pressure loss by viscous friction**

constant loss coefficient (default) | correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss by viscous friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (TL) block for the calculations by parameterization.

**Pressure loss coefficient — Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | unitless scalar

Aggregate loss coefficient for all flow resistances in the flow channel—including the wall friction responsible for major loss and the local resistances, due to bends, elbows, and other geometry changes, responsible for minor loss.

The loss coefficient is an empirical dimensionless number commonly used to express the pressure loss due to viscous friction. It can be calculated from experimental data or, in some cases, obtained from product data sheets.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Constant loss coefficient.

**Length of flow path from inlet to outlet — Distance traveled from port to port**

1 m (default) | unitless scalar with units of length

Total distance the flow must travel to reach across the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels in which the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to viscous friction at the wall.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes and Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances — Aggregate minor pressure loss expressed as a length**

0.1 m (default) | scalar with units of length

Aggregate minor pressure loss expressed as a length. This length is that which all local resistances, such as elbows, tees, and unions, would add to the flow path if in their place was a simple wall extension. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.



**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Internal surface absolute roughness — Mean height of surface protrusions behind wall friction**

15e-6 m (default) | scalar with units of length

Mean height of the surface protrusions from which wall friction arises. Higher protrusions mean a rougher wall for more friction and so a steeper pressure loss. Surface roughness features in the Haaland correlation from which the Darcy friction factor derives and on which the pressure loss calculation depends.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Laminar friction constant for Darcy friction factor — Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | unitless scalar

Pressure loss correction for flow cross section in laminar flow conditions. This parameter is commonly referred to as the shape factor. Its ratio to the Reynolds number gives the Darcy friction factor for the pressure loss calculation in the laminar zone. The default value belongs to cylindrical pipes and tubes.

The shape factor derives for certain shapes from the solution of the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96, as does a slender conduit between parallel plates.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Correlations for tubes.

**Reynolds number vector for Darcy friction factor — Reynolds number at each breakpoint in lookup table for Darcy friction factor**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Darcy friction factor. The block interpolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB linear type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Darcy friction factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector – Darcy friction factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Darcy friction factor at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Darcy friction factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Darcy friction factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Darcy friction factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Darcy friction factor vs. Reynolds number`.

**Reynolds number vector for Euler number – Reynolds number at each breakpoint in lookup table for Euler number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Euler number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Euler number vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Euler number vs. Reynolds number`.

**Euler number vector – Euler number at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Euler number at each breakpoint in its lookup table over the Reynolds number. The block interpolates and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Euler numbers must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Euler number** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Pressure loss parameterization** setting of `Tabulated data - Euler number vs. Reynolds number`.

**Heat transfer parameterization – Mathematical model for heat transfer between fluid and wall**

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Mathematical model for heat transfer between fluid and wall. The choice of model determines which expressions to apply and which parameters to specify for heat transfer calculation. See the E-NTU Heat Transfer block for the calculations by parameterization.

**Heat transfer surface area – Effective surface area used in heat transfer between fluid and wall**

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Effective surface area used in heat transfer between fluid and wall. The effective surface area is the sum of primary and secondary surface areas, or those of the wall, where it is exposed to fluid, and of the fins, if any are used. Fin surface area is normally scaled by a fin efficiency factor.

**Liquid-wall heat transfer coefficient – Heat transfer coefficient for convection between fluid and wall**

0.4 m<sup>2</sup> (default) | unitless scalar

Heat transfer coefficient for convection between fluid and wall. Resistance due to fouling is captured separately in the **Fouling factor** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Constant heat transfer coefficient.

**Length of flow path for heat transfer – Characteristic length traversed in heat transfer between fluid and wall**

1 m (default) | scalar with units of length

Characteristic length traversed in heat transfer between fluid and wall. This length factors in the calculation of the hydraulic diameter from which the heat transfer coefficient and the Reynolds number, as defined in the tabulated heat transfer parameterizations, derives.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow**

3.66 (default) | positive unitless scalar

Constant assumed for Nusselt number in laminar flow. The Nusselt number factors in the calculation of the heat transfer coefficient between fluid and wall, on which the heat transfer rate depends. The default value belongs to cylindrical pipes and tubes.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Correlations for tubes.

**Reynolds number vector for Colburn factor — Values of the Reynolds number at which to specify the Colburn factor data**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Colburn factor. The block inter- and extrapolates the breakpoints to obtain the Colburn factor at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. Their number must equal the size of the **Colburn factor vector** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

**Colburn factor vector — Colburn factor at each breakpoint in lookup table over Reynolds number**

unitless numerical array

Colburn factor at each breakpoint in its lookup table over the Reynolds number. The block inter- and extrapolates the breakpoints to obtain the Euler number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Colburn factors must not be negative and they must align from left to right in order of increasing Reynolds number. Their number must equal the size of the **Reynolds number vector for Colburn factor** parameter, with which they are to combine to complete the tabulated breakpoints.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Colburn factor vs. Reynolds number.

**Reynolds number vector for Nusselt number — Reynolds number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Reynolds number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Reynolds number. Interpolation is the MATLAB `linear` type and extrapolation is nearest.

The Reynolds numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of rows in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Reynolds number vector must be  $m$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Prandtl number vector for Nusselt number — Prandtl number at each breakpoint in lookup table for Nusselt number**

unitless numerical array

Prandtl number at each breakpoint in the lookup table for the Nusselt number. The table is two-way, with both Reynolds and Prandtl numbers serving as independent coordinates. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any Prandtl number. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`.

The Prandtl numbers must be greater than zero and increase monotonically from left to right. They can span across laminar, transient, and turbulent zones. The size of the vector must equal the number of columns in the **Nusselt number table** parameter. If the table has  $m$  rows and  $n$  columns, the Prandtl number vector must be  $n$  elements long.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number table, Nu (Re,Pr) — Nusselt number at each breakpoint in lookup table over Reynolds and Prandtl numbers**

unitless numerical array

Nusselt number at each breakpoint in its lookup table over the Reynolds and Prandtl numbers. The block inter- and extrapolates the breakpoints to obtain the Nusselt number at any pair of Reynolds and Prandtl numbers. Interpolation is the MATLAB `linear` type and extrapolation is `nearest`. By determining the Nusselt number, the table feeds the calculation from which the heat transfer coefficient between fluid and wall derives.

The Nusselt numbers must be greater than zero. They must align from top to bottom in order of increasing Reynolds number and from left to right in order of increasing Prandtl numbers. The number of rows must equal the size of the **Reynolds number vector for Nusselt number** parameter, and the number of columns must equal the size of the **Prandtl number vector for Nusselt number** parameter.

**Dependencies**

This parameter applies solely to the **Heat transfer parameterization** setting of Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Fouling factor — Measure of thermal resistance due to fouling deposits**

1.6e-4 K/W (default) | scalar with units of temperature over power

Measure of thermal resistance due to fouling deposits which over time tend to build on the exposed surfaces of the wall. The deposits, as they impose between the fluid and wall a new solid layer through which heat must traverse, add to the heat transfer path an extra thermal resistance. Fouling deposits grow slowly and the resistance due to them is accordingly assumed constant during simulation.

**Minimum fluid-wall heat transfer coefficient — Lower bound for the heat transfer coefficient**100 W/(m<sup>2</sup> \* K) (default) | scalar with units of power/area/temperature

Lower bound for the heat transfer coefficient between fluid and wall. If calculation returns a lower heat transfer coefficient, this bound replaces the calculated value.

## Effects and Initial Conditions

### **Thermal liquid dynamic compressibility – Option to model pressure dynamics in the thermal liquid channel**

On (default) | Off

Option to model the pressure dynamics in the thermal liquid 1 or thermal liquid 2 channel. Setting this parameter to Off removes the pressure derivative terms from the component energy and mass conservation equations. The pressure inside the heat exchanger is then reduced to the weighted average of the two port pressures.

### **Thermal Liquid initial temperature – Temperature in the thermal liquid 1 or thermal liquid 2 channel at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the thermal liquid 1 or thermal liquid 2 channel at the start of simulation.

### **Thermal Liquid 1|2 initial pressure – Pressure in the thermal liquid 1 or thermal liquid 2 channel at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the thermal liquid 1 or thermal liquid 2 channel at the start of simulation.

## Version History

Introduced in R2016a

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

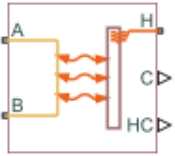
## See Also

E-NTU Heat Transfer | Heat Exchanger Interface (TL) | Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (TL)

# Heat Exchanger Interface (TL)

Thermal interface between a thermal liquid and its surroundings

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



## Description

The Heat Exchanger Interface (TL) block models the pressure drop and temperature change between the thermal liquid inlet and outlet of a thermal interface. Combine with the E-NTU Heat Transfer block to model the heat transfer rate across the interface between two fluids.

### Mass Balance

The form of the mass balance equation depends on the dynamic compressibility setting. If the **Fluid dynamic compressibility** parameter is set to Off, the mass balance equation is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  and  $\dot{m}_B$  are the mass flow rates into the interface through ports A and B.

If the **Fluid dynamic compressibility** parameter is set to On, the mass balance equation is

$$\dot{m}_A + \dot{m}_B = \left( \frac{dp}{dt} \frac{1}{\beta} - \frac{dT}{dt} \alpha \right) \rho V,$$

where:

- $p$  is the pressure of the thermal liquid volume.
- $T$  is the temperature of the thermal liquid volume.
- $\alpha$  is the isobaric thermal expansion coefficient of the thermal liquid volume.
- $\beta$  is the isothermal bulk modulus of the thermal liquid volume.
- $\rho$  is the mass density of the thermal liquid volume.
- $V$  is the volume of thermal liquid in the heat exchanger interface.

### Momentum Balance

The momentum balance in the heat exchanger interface depends on the fluid dynamic compressibility setting. If the **Fluid dynamic compressibility** parameter is set to On, the momentum balance factors in the internal pressure of the heat exchanger interface explicitly. The momentum balance in the half volume between port A and the internal interface node is computed as

$$p_A - p = \Delta p_{\text{Loss},A},$$

while in the half volume between port B and the internal interface node it is computed as

$$p_B - p = \Delta p_{Loss,B},$$

where:

- $p_A$  and  $p_B$  are the pressures at ports A and B.
- $p$  is the pressure in the internal node of the interface volume.
- $\Delta p_{Loss,A}$  and  $\Delta p_{Loss,B}$  are the pressure losses between port A and the internal interface node and between port B and the internal interface node.

If the **Fluid dynamic compressibility** parameter is set to **Off**, the momentum balance in the interface volume is computed directly between ports A and B as

$$p_A - p_B = \Delta p_{Loss,A} - \Delta p_{Loss,B}.$$

### Pressure Loss Calculations

The exact form of the pressure loss terms depends on the **Pressure loss parameterization** setting in the block dialog box. If the pressure loss parameterization is set to **Constant loss coefficient**, the pressure loss in the half volume adjacent to port A is

$$\Delta p_{Loss,A} = \begin{cases} \dot{m}_A \mu_A (CP)_{Loss} Re_L \frac{1}{4D_{h,p} \rho_A S_{Min}}, & Re_A \leq Re_L \\ (CP)_{Loss} \frac{\dot{m}_A |\dot{m}_A|}{4\rho_A S_{Min}^2}, & Re_A \geq Re_T \end{cases},$$

while in the half volume adjacent to port B it is

$$\Delta p_{Loss,B} = \begin{cases} \dot{m}_B \mu_B (CP)_{Loss} Re_L \frac{1}{4D_{h,p} \rho_B S_{Min}}, & Re_B \leq Re_L \\ (CP)_{Loss} \frac{\dot{m}_B |\dot{m}_B|}{4\rho_B S_{Min}^2}, & Re_B \geq Re_T \end{cases},$$

where:

- $\mu_A$  and  $\mu_B$  are the fluid dynamic viscosities at ports A and B.
- $CP_{Loss}$  is the **Pressure loss coefficient** parameter specified in the block dialog box.
- $Re_L$  is the Reynolds number upper bound for the laminar flow regime.
- $Re_T$  is the Reynolds number lower bound for the turbulent flow regime.
- $D_{h,p}$  is the hydraulic diameter for pressure loss calculations.
- $\rho_A$  and  $\rho_B$  are the fluid mass densities at ports A and B.
- $S_{Min}$  is the total minimum free-flow area.

If the pressure loss parameterization is set to **Correlations for tubes**, the pressure loss in the half volume adjacent to port A is

$$\Delta p_{Loss,A} = \begin{cases} \dot{m}_A \mu_A \lambda \frac{(L_{press} + L_{add})}{4D_{h,p} \rho_A S_{Min}}, & Re_A \leq Re_L \\ f_{T,A} \frac{(L_{press} + L_{add})}{4D_{h,p}} \frac{\dot{m}_A |\dot{m}_A|}{\rho_A S_{Min}^2}, & Re_A \geq Re_T \end{cases},$$



while in the half volume adjacent to port B it is

$$\Delta p_{Loss, B} = \begin{cases} \dot{m}_B \mu_B \lambda \frac{(L_{press} + L_{add})}{4D_{h,p} \rho_B S_{Min}}, & Re_B \leq Re_L \\ f_{T,B} \frac{(L_{press} + L_{add})}{4D_{h,p}} \frac{\dot{m}_B |\dot{m}_B|}{\rho_B S_{Min}^2}, & Re_B \geq Re_T \end{cases},$$

where:

- $L_{press}$  is the flow path length from inlet to outlet.
- $L_{add}$  is the aggregate equivalent length of local resistances.
- $f_{T,A}$  and  $f_{T,B}$  are the turbulent-regime Darcy friction factors at ports A and B.

The Darcy friction factor in the half volume adjacent to port A is

$$f_{T,A} = \frac{1}{\left[ -1.8 \log_{10} \left( \frac{6.9}{Re_A} + \frac{r}{3.7D_{h,p}} \right)^{1.11} \right]^2},$$

while in the half volume adjacent to port B it is

$$f_{T,B} = \frac{1}{\left[ -1.8 \log_{10} \left( \frac{6.9}{Re_B} + \frac{r}{3.7D_{h,p}} \right)^{1.11} \right]^2},$$

where:

- $r$  is the internal surface absolute roughness.

If the pressure loss parameterization is set to **Tabulated data – Darcy friction factor vs. Reynolds number**, the pressure loss in the half volume adjacent to port A is

$$\Delta p_{Loss, A} = \begin{cases} \dot{m}_A \mu_A \lambda \frac{L_{press}}{4D_{h,p}^2 \rho_A S_{Min}}, & Re_A \leq Re_L \\ f(Re_A) \frac{L_{press}}{4D_{h,p}} \frac{\dot{m}_A |\dot{m}_A|}{\rho_A S_{Min}^2}, & Re_A \geq Re_T \end{cases},$$

while in the half volume adjacent to port B it is

$$\Delta p_{Loss, B} = \begin{cases} \dot{m}_B \mu_B \lambda \frac{L_{press}}{4D_{h,p}^2 \rho_B S_{Min}}, & Re_B \leq Re_L \\ f(Re_B) \frac{L_{press}}{4D_{h,p}} \frac{\dot{m}_B |\dot{m}_B|}{\rho_B S_{Min}^2}, & Re_B \geq Re_T \end{cases},$$

where:

- $\lambda$  is the shape factor for laminar flow viscous friction.
- $f(Re_A)$  and  $f(Re_B)$  are the Darcy friction factors at ports A and B. The block obtains the friction factors from tabulated data specified relative to the Reynolds number.

If the pressure loss parameterization is set to **Tabulated data – Euler number vs. Reynolds number**, the pressure loss in the half volume adjacent to port A is

$$\Delta p_{Loss, A} = \begin{cases} \dot{m}_A \mu_A Eu(Re_L) Re_L \frac{1}{4D_{h, p} \rho_A S_{Min}}, & Re_A \leq Re_L \\ Eu(Re_A) \frac{\dot{m}_A |\dot{m}_A|}{4\rho_A S_{Min}^2}, & Re_A \geq Re_T \end{cases},$$

while in the half volume adjacent to port B it is

$$\Delta p_{Loss, B} = \begin{cases} \dot{m}_B \mu_B Eu(Re_L) Re_L \frac{1}{4D_{h, p} \rho_B S_{Min}}, & Re_B \leq Re_L \\ Eu(Re_B) \frac{\dot{m}_B |\dot{m}_B|}{4\rho_B S_{Min}^2}, & Re_B \geq Re_T \end{cases},$$

where:

- $Eu(Re_L)$  is the Euler number at the Reynolds number upper bound for laminar flows.
- $Eu(Re_A)$  and  $Eu(Re_B)$  are the Euler numbers at ports A and B. The block obtains the Euler numbers from tabulated data specified relative to the Reynolds number.

### Energy Balance

The energy balance in the heat exchanger interface depends on the fluid dynamic compressibility setting. If the **Fluid dynamic compressibility** parameter is set to **On**, the energy balance is

$$\frac{dp}{dt} \frac{dU}{dp} + \frac{dT}{dt} \frac{dU}{dT} = \Phi_A + \Phi_B + Q_H,$$

where:

- $U$  is the internal energy contained in the volume of the heat exchanger interface.
- $\Phi_A$  and  $\Phi_B$  are the energy flow rates through ports **A** and **B** into the volume of the heat exchanger interface.
- $Q_H$  is the heat flow rate through port **H**, representing the interface wall, into the volume of the heat exchange interface.

The internal energy derivatives are defined as

$$\frac{dU}{dp} = \left[ \frac{1}{\beta} (\rho u + p) - T\alpha \right] V$$

and

$$\frac{dU}{dT} = \left[ c_p - \alpha \left( u + \frac{p}{\rho} \right) \right] \rho V,$$

where  $u$  is the specific internal energy of the thermal liquid, or the internal energy contained in a unit mass of the same.

If the **Fluid dynamic compressibility** parameter is set to **Off**, the thermal liquid density is treated as a constant. The bulk modulus is then effectively infinite and the thermal expansion coefficient zero. The pressure and temperature derivatives of the compressible case vanish and the energy balance is restated as

$$\frac{dE}{dt} = \phi_A + \phi_B + Q_H,$$

where  $E$  is the total internal energy of the incompressible thermal liquid, or

$$E = \rho u V.$$

### Heat Transfer Correlations

The block calculates and outputs the liquid-wall heat transfer coefficient value. The calculation depends on the **Heat transfer coefficient specification** setting in the block dialog box. If the heat transfer coefficient specification is **Constant heat transfer coefficient**, the heat transfer coefficient is simply the constant value specified in the block dialog box,

$$h_{L-W} = h_{Const},$$

where:

- $h_{L-W}$  is the liquid-wall heat transfer coefficient.
- $h_{Const}$  is the **Liquid-wall heat transfer coefficient value** specified in the block dialog box.

For all other heat transfer coefficient parameterizations, the heat transfer coefficient is defined as the arithmetic average of the port heat transfer coefficients:

$$h_{L-W} = \frac{h_A + h_B}{2},$$

where:

- $h_A$  and  $h_B$  are the liquid-wall heat transfer coefficients at ports A and B.

The heat transfer coefficient at port A is

$$h_A = \frac{Nu_A k_A}{D_{h,heat}},$$

while at port B it is

$$h_B = \frac{Nu_B k_B}{D_{h,heat}},$$

where:

- $Nu_A$  and  $Nu_B$  are the Nusselt numbers at ports A and B.
- $k_A$  and  $k_B$  are the thermal conductivities at ports A and B.
- $D_{h,heat}$  is the hydraulic diameter for heat transfer calculations.

The hydraulic diameter used in heat transfer calculations is defined as

$$D_{h,heat} = \frac{4S_{Min}L_{heat}}{S_{heat}},$$

where:

- $L_{heat}$  is the flow path length used in heat transfer calculations.

- $S_{\text{heat}}$  is the total heat transfer surface area.

### Nusselt Number Calculations

The Nusselt number calculation depends on the **Heat transfer coefficient specification** setting in the block dialog box. If the heat transfer specification is set to **Correlations for tubes**, the Nusselt number at port A is

$$Nu_A = \begin{cases} Nu_L, & Re_A \leq Re_L \\ \frac{(f_{T,A/8})(Re_A - 1000)Pr_A}{1 + 12.7(f_{T,A/8})^{1/2}(Pr_B^{2/3} - 1)}, & Re_A \geq Re_T' \end{cases}$$

while at port B it is

$$Nu_B = \begin{cases} Nu_L, & Re_B \leq Re_L \\ \frac{(f_{T,B/8})(Re_B - 1000)Pr_B}{1 + 12.7(f_{T,B/8})^{1/2}(Pr_B^{2/3} - 1)}, & Re_B \geq Re_T' \end{cases}$$

where:

- $Nu_L$  is the **Nusselt number for laminar flow heat transfer** value specified in the block dialog box.
- $Pr_A$  and  $Pr_B$  are the Prandtl numbers at ports A and B.

If the heat transfer specification is set to **Tabulated data – Colburn data vs. Reynolds number**, the Nusselt number at port A is

$$Nu_A = j(Re_{A,heat})Re_{A,heat}Pr_A^{1/3},$$

while at port B it is

$$Nu_B = j(Re_{B,heat})Re_{B,heat}Pr_B^{1/3},$$

where:

- $j(Re_{A,heat})$  and  $j(Re_{B,heat})$  are the Colburn numbers at ports A and B. The block obtains the Colburn numbers from tabulated data provided as a function of the Reynolds number.
- $Re_{A,heat}$  and  $Re_{B,heat}$  are the Reynolds numbers based on the hydraulic diameters for heat transfer calculations at ports A and B. This parameter is defined at port A as

$$Re_{A,heat} = \frac{\dot{m}_A D_{h,heat}}{S_{Min} \mu_A},$$

and at port B as

$$Re_B = \frac{\dot{m}_B D_{h,heat}}{S_{Min} \mu_B}.$$

If the heat transfer specification is set to **Tabulated data – Nusselt number vs. Reynolds number & Prandtl number**, the Nusselt number at port A is

$$Nu_A = Nu(Re_{A,heat}, Pr_A),$$

while at port B it is

$$Nu_B = Nu(Re_{B,heat}, Pr_B).$$

### Hydraulic Diameter Calculations

The hydraulic diameter used in heat transfer calculations can differ from the hydraulic diameter employed in pressure loss calculations, and are different if the heated and friction perimeters are not the same. For a concentric pipe heat exchanger with an annular cross-section, the hydraulic diameter for heat transfer calculations is

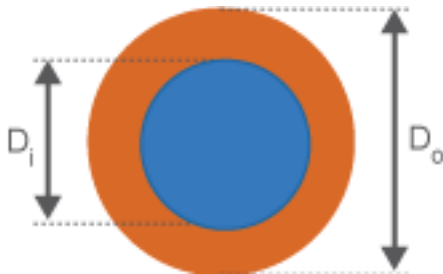
$$D_{h,heat} = \frac{4(\pi/4)(D_o^2 - D_i^2)}{\pi D_i} = \frac{D_o^2 - D_i^2}{D_i},$$

while the hydraulic diameter for pressure calculations is

$$D_{h,p} = \frac{4(\pi/4)(D_o^2 - D_i^2)}{\pi(D_i + D_o)} = D_o - D_i,$$

where:

- $D_o$  is the outer annulus diameter.
- $D_i$  is the inner annulus diameter.



### Annulus Schematic

The difference between the outer diameter and the inner diameter depicted in orange represents the thermal liquid. The blue region within the inner diameter is the fluid that exchanges heat with the thermal liquid.

## Ports

### Output

#### C – Heat capacity rate

physical signal

Physical signal output port for the thermal capacity rate of the thermal liquid

#### HC – Heat transfer coefficient

physical signal

Physical signal output port for the heat transfer coefficient between the thermal liquid and the interface wall

## Conserving

### **A – Thermal liquid port**

thermal liquid

Thermal liquid conserving port representing the thermal liquid inlet

### **B – Thermal liquid port**

thermal liquid

Thermal liquid conserving port representing the thermal liquid outlet

### **H – Thermal inlet temperature**

thermal

Thermal conserving port associated with the thermal liquid inlet temperature

## Parameters

### **Minimum free-flow area – Cross-sectional area of flow channel at its narrowest point**

0.01 m<sup>2</sup> (default) | scalar

Aggregate flow area free of obstacles based on the smallest tube spacing or corrugation pitch.

### **Hydraulic diameter for pressure loss – Diameter or equivalent diameter of channel**

0.1 m (default) | scalar

Hydraulic diameter of the tubes or channels comprising the heat exchange interface. The hydraulic diameter is the ratio of the flow cross-sectional area to the channel perimeter.

### **Thermal liquid volume – Total volume of fluid contained in flow channel**

0.01 m<sup>3</sup> (default) | scalar with units of length squared

Total volume of the fluid contained in the thermal liquid flow channel.

### **Laminar flow upper Reynolds number limit – Start of transition between laminar and turbulent regimes**

2000 (default) | scalar

Start of the transition from the laminar regime to the turbulent regime. Above this number, inertial forces become increasingly dominant. The default value is given for circular pipes and tubes with smooth surfaces.

### **Turbulent flow lower Reynolds number limit – End of transition between laminar and turbulent regimes**

4000 (default) | scalar

End of the transition from the laminar regime to the turbulent regime. Below this number, viscous forces become increasingly dominant.

### **Pressure loss parameterization – Mathematical model for pressure loss due to friction**

Constant loss coefficient (default) | Correlations for tubes | Tabulated data - Darcy friction factor vs. Reynolds number | Tabulated data - Euler number vs. Reynolds number

Mathematical model for pressure loss due to friction. This setting determines which expressions to use for calculation and which block parameters to specify as input. See the Heat Exchanger Interface (TL) blocks for the calculations by parameterization.

**Pressure loss coefficient – Aggregate loss coefficient for all flow resistances between the ports**

0.1 (default) | scalar

Aggregate loss coefficient for all flow resistances in the flow channel, including wall friction (major losses) and local resistances due to bends, elbows, and other geometry changes (minor losses).

The loss coefficient is an empirical, dimensionless number used to express the pressure losses due to friction. It can be calculated from experimental data or obtained from product data sheets.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Constant loss coefficient.

**Length of flow path from inlet to outlet – Distance traveled from port to port**

1 m (default) | scalar with units of length

Total distance the flow must travel between the ports. In multi-pass shell-and-tube exchangers, the total distance is the sum over all shell passes. In tube bundles, corrugated plates, and other channels where the flow is split into parallel branches, it is the distance covered in a single branch. The longer the flow path, the steeper the major pressure loss due to friction at the wall.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes or Tabulated data - Darcy friction factor vs Reynolds number.

**Aggregate equivalent length of local resistances – Aggregate minor pressure loss expressed in length**

0.1 m (default) | scalar

Aggregate minor pressure loss, expressed as a length. The length of a straight channel results in equivalent losses to the sum of existing local resistances from elbows, tees, and unions. The larger the equivalent length, the steeper the minor pressure loss due to the local resistances.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

**Internal surface absolute roughness – Mean height of wall surface variations that contribute to frictional losses**

15e-6 m (default) | scalar with units of length

Average height of all surface defects on the internal surface of the pipe. The surface roughness enables the calculation of the friction factor in the turbulent flow regime.

**Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

**Laminar friction constant for Darcy friction factor – Pressure loss correction for flow cross section in laminar flow conditions**

64 (default) | scalar

Pressure loss correction for laminar flow. This parameter is referred to as the shape factor, and can be used to derive the Darcy friction factor for pressure loss calculations in the laminar regime. The default value is for cylindrical pipes and tubes.

Some additional shape factors for non-circular cross-sections can be determined from analytical solutions to the Navier-Stokes equations. A square duct has a shape factor of 56, a rectangular duct with an aspect ratio of 2:1 has a shape factor of 62, and an annular tube has a shape factor of 96. A slender conduit between parallel plates also has a shape factor of 96.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Correlations for tubes.

#### **Reynolds number vector for Darcy friction factor – Reynolds number at each breakpoint in Darcy friction factor lookup table**

[400, 1000, 1500, 3000, 4000, 6000, 10000, 20000, 40000, 60000, 100000, 100000000] (default) | array

Vector of Reynolds numbers at which to specify the Darcy friction factor. The block uses this vector to create a lookup table for the Darcy friction factor.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

#### **Darcy friction factor vector – Darcy friction factor at each breakpoint in Reynolds number lookup table**

[.264, .112, .071, .0417, .0387, .0268, .025, .0232, .0226, .022, .0214, .0214] (default) | array

Vector of Darcy friction factors corresponding to the values specified in the **Reynolds number vector for Darcy friction factor** parameter. The block uses this vector to create a lookup table for the Darcy friction factor.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

#### **Reynolds number vector for Euler number – Reynolds number at each breakpoint in the Euler number lookup table**

[50, 500, 1000, 2000] (default) | array

Vector of Reynolds numbers at which to specify the Euler number. The block uses this vector to create a lookup table for the Euler number.

#### **Dependencies**

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Euler number vs. Reynolds number.

#### **Euler number vector – Euler number at each breakpoint in the Reynolds number lookup table**

[4.4505, .6864, .4791, .3755] (default) | array



Vector of Euler numbers corresponding to the values specified in the **Reynolds number vector for Euler number** parameter. The block uses this vector to create a lookup table for the Euler number.

#### Dependencies

To enable this parameter, set **Pressure loss parameterization** to Tabulated data - Euler number vs. Reynolds number.

#### Heat transfer parameterization – Mathematical model for heat transfer between fluid and wall

Constant heat transfer coefficient (default) | Correlations for tubes | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Parameterization used to compute the heat transfer rate between the heat exchanger fluids. You can assume a constant loss coefficient, use empirical correlations for tubes, or specify tabulated data for the Colburn or Nusselt number.

#### Liquid-wall heat transfer coefficient – Heat transfer coefficient for convection between fluid and wall

100 W/(m<sup>2</sup> \* K) (default) | scalar

Heat transfer coefficient between the thermal liquid and the heat-transfer surface.

#### Dependencies

To enable this parameter, set **Heat transfer parameterization** to Constant heat transfer coefficient.

#### Heat transfer surface area – Effective surface area used in heat transfer between fluid and wall

0.4 m<sup>2</sup> (default) | scalar with units of length squared

Aggregate surface area available for heat transfer between the heat exchanger fluids.

#### Length of flow path for heat transfer – Characteristic length traversed in heat transfer between fluid and wall

1 m (default) | scalar with units of length

Distance traversed by the fluid along which heat exchange takes place.

#### Dependencies

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number or Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

#### Nusselt number for laminar flow heat transfer – Constant assumed for Nusselt number in laminar flow

3.66 (default) | positive scalar

Proportionality constant between convective and conductive heat transfer in the laminar regime. This parameter enables the calculation of convective heat transfer rates in laminar flows. The appropriate value to use depends on component geometry.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Correlations for tubes.

**Reynolds number vector for Colburn factor – Reynolds number at each breakpoint in Colburn factor lookup table**

[100, 150, 1000] (default) | array

Vector of Reynolds numbers at which to specify the Colburn factor. The block uses this vector to create a lookup table for the Colburn number. The number of values in this vector must be equal to the size of the **Colburn factor vector** parameter to calculate tabulated breakpoints.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number.

**Colburn factor vector – Colburn factor at each breakpoint in Reynolds number lookup table**

[.019, .013, .002] (default) | array

Vector of Colburn factors corresponding to the values specified in the **Reynolds number vector for Colburn number** parameter. The block uses this vector to create a lookup table for the Colburn factor.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number.

**Reynolds number vector for Nusselt number – Reynolds number at each breakpoint in Nusselt number lookup table**

[100, 150, 1000] (default) | array

Vector of Reynolds numbers at which to specify the Nusselt number. The block uses this vector to create a lookup table for the Nusselt number.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Prandtl number vector for Nusselt number – Prandtl number at each breakpoint in the Nusselt number lookup table**

[1, 10] (default) | array

Vector of Prandtl numbers at which to specify the Nusselt number. The block uses this vector to create a lookup table for the Nusselt number.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number table,  $Nu(Re, Pr)$  – Nusselt number at each breakpoint in Reynolds-Prandtl number lookup table**

[3.72, 4.21; 3.75, 4.44; 4.21, 7.15] (default) | array

Matrix of Nusselt numbers corresponding to the values specified in the **Reynolds number vector for Nusselt number** and **Prandtl number vector for Nusselt number** parameters. The block uses this vector to create a lookup table for the Nusselt factor.

### Dependencies

To enable this parameter, set **Heat transfer parameterization** to `Tabulated data - Nusselt number vs. Reynolds number & Prandtl number`.

### Fouling factor — Increased resistance due to fouling

$1e-4 \text{ m}^2\text{K/W}$  (default) | scalar

Empirical parameter used to quantify the increased thermal resistance due to dirt deposits on the heat transfer surface.

### Effects and Initial Conditions

#### Thermal Liquid dynamic compressibility — Setting for liquid compressibility in heat exchanger

`On` (default) | `Off` | scalar

Option to model the pressure dynamics inside the heat exchanger. Setting this parameter to `Off` removes the pressure derivative terms from the component energy and mass conservation equations. The pressure inside the heat exchanger is then reduced to the weighted average of the two port pressures.

#### Thermal Liquid initial temperature — Initial temperature of thermal liquid

$293.15 \text{ K}$  (default) | scalar

Temperature of the internal volume of thermal liquid at the start of simulation.

#### Thermal Liquid initial temperature — Initial pressure of thermal liquid

$0.101325 \text{ MPa}$  (default) | scalar

Pressure of the internal volume of thermal liquid at the start of simulation.

## Version History

Introduced in R2016a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

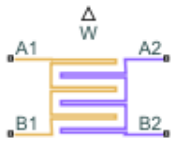
## See Also

E-NTU Heat Transfer | Heat Exchanger Interface (G)

## Heat Exchanger (TL-MA)

Models heat exchange between a moist air network and a thermal liquid network

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The Heat Exchanger (TL-MA) block models a heat exchanger with one moist air network, which flows between ports **A2** and **B2**, and one thermal liquid network, which flows between ports **A1** and **B1**. The fluid streams can be aligned in parallel, counter, or cross-flow configurations.

A thermal liquid-moist air heat exchanger is not appropriate for refrigeration cooling systems. See Condenser Evaporator (2P-MA) or Condenser Evaporator (TL-2P) for heat exchangers that can be employed in refrigeration applications.

You can model the moist air side as flow within tubes, flow around thermal liquid tubing, or by an empirical, generic parameterization. The moist air side comprises air, trace gas, and water vapor that may condense throughout the heat exchange cycle. The block model accounts for the latent heat that is released when water condenses on the heat transfer surface. This liquid layer does not collect on the surface and is assumed to be completely removed from the downstream moist air flow. The moisture condensation rate is returned as a physical signal at port **W**.

The block uses the Effectiveness-NTU (E-NTU) method to model heat transfer through the shared wall. Fouling on the exchanger walls, which increases thermal resistance and reduces the heat exchange between the two fluids, is also modeled. You can also optionally model fins on both the moist air and thermal liquid sides. Pressure loss due to viscous friction on both sides of the exchanger can be modeled analytically or by generic parameterization, which you can use to tune to your own data.

You can model the thermal liquid side as flow within tubes, flow around moist air tubing, or by an empirical, generic parameterization.

### Heat Exchanger Configuration

The heat exchanger effectiveness is based on the selected heat exchanger configuration, the fluid properties, the tube geometry and flow configuration on each side of the exchanger, and the usage and size of fins.

### Flow Arrangement

The **Flow arrangement** parameter assigns the relative flow paths between the two sides:

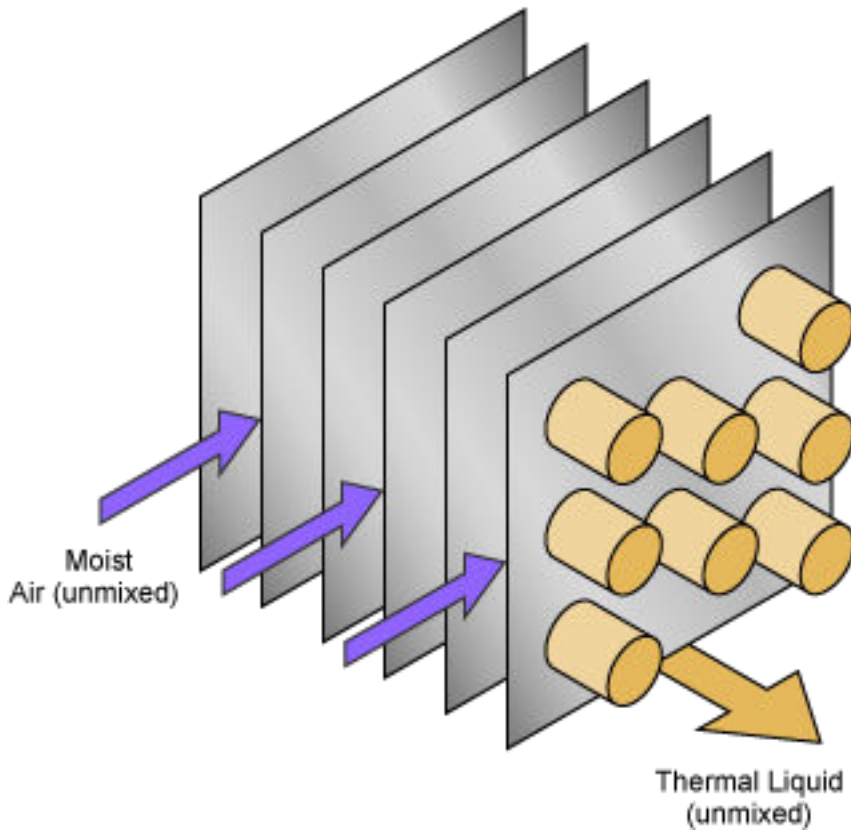
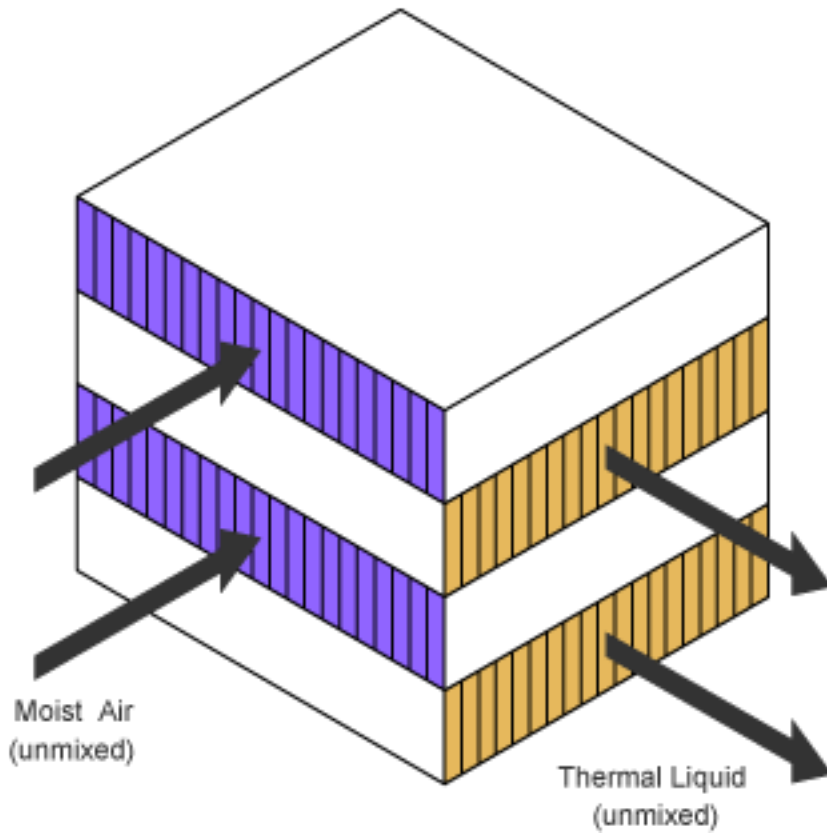
- `Parallel` flow indicates the fluids are moving in the same direction.

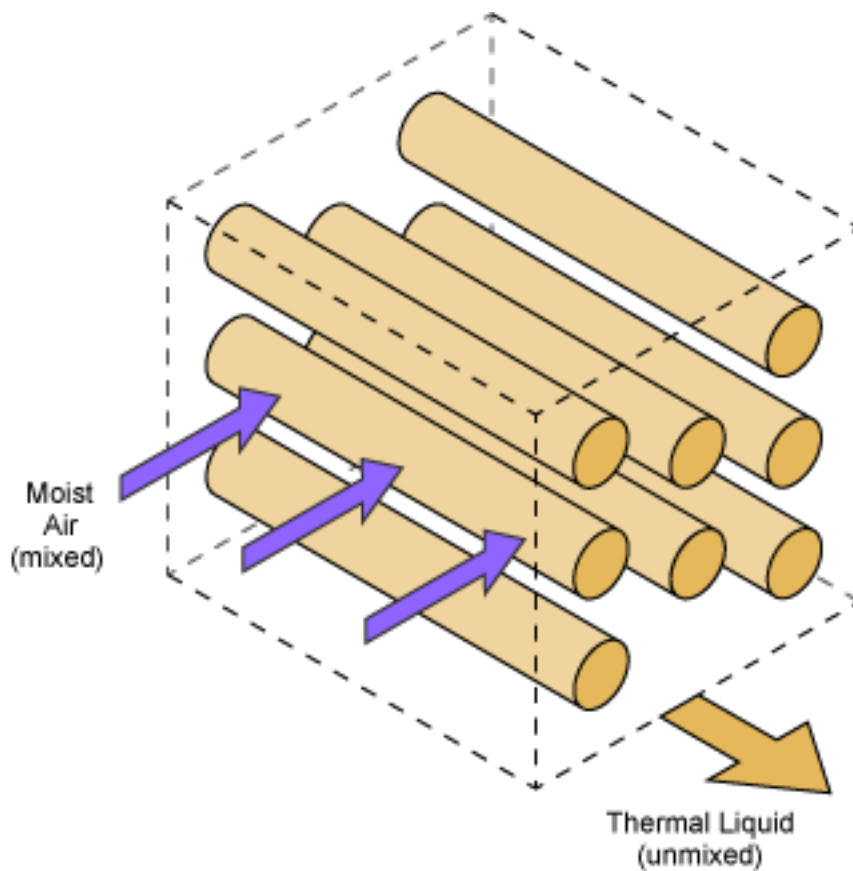
- Counter flow indicates the fluids are moving in parallel, but opposite directions.
- Cross flow indicates the fluids are moving perpendicular to each other.

**Thermal Mixing**

When **Flow arrangement** is set to Cross flow, use the **Cross flow arrangement** parameter to indicate whether the thermal liquid or moist air flows are separated into multiple paths by baffles or walls. Without these separations, the flow can mix freely and is considered *mixed*. Both fluids, one fluid, or neither fluid can be mixed in the cross-flow arrangement. Mixing homogenizes the fluid temperature along the direction of flow of the second fluid, and varies perpendicular to the second fluid flow.

Unmixed flows vary in temperature both along and perpendicular to the flow path of the second fluid.



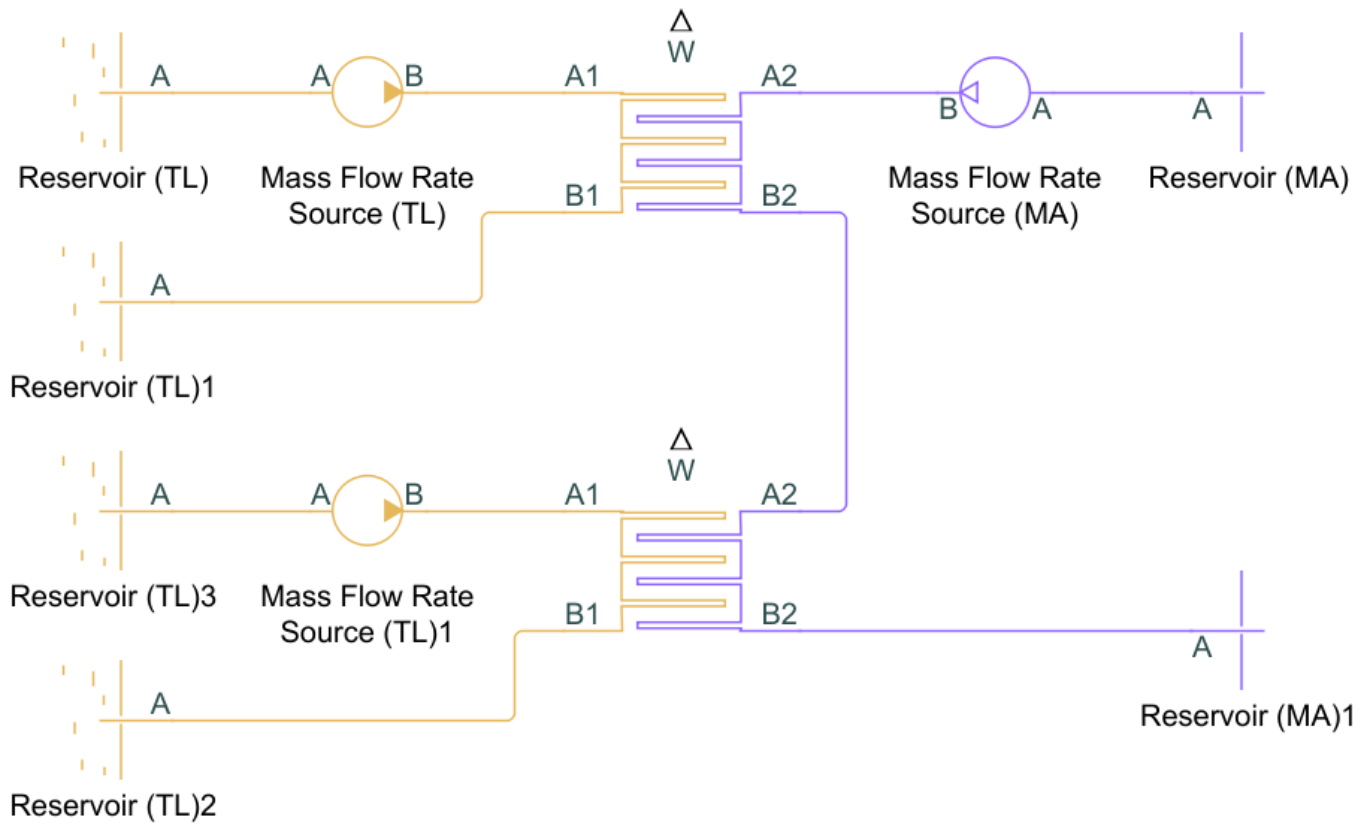


### Sample Cross-Flow Configurations

Note that the flow direction during simulation does not impact the selected flow arrangement setting. The ports on the block do not reflect the physical positions of the ports in the physical heat exchange system.

All flow arrangements are single-pass, which means that the fluids do not make multiple turns in the exchanger for additional points of heat transfer. To model a multi-pass heat exchanger, you can arrange multiple Heat Exchanger (TL-MA) blocks in series or in parallel.

For example, to achieve a two-pass configuration on the moist air side and a single-pass configuration on the thermal liquid side, you can connect the moist air sides in series and the thermal liquid sides to the same input in parallel (such as two Mass Flow Rate Source blocks with half of the total mass flow rate), as shown below.



### Flow Geometry

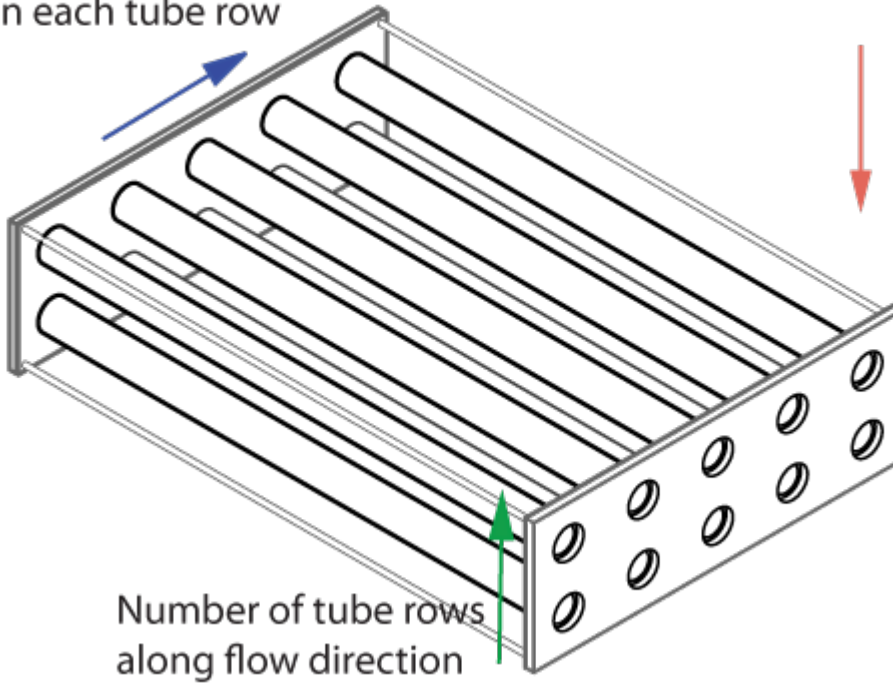
The **Flow geometry** parameter sets the flow arrangement of the fluid of the respective dialog tab as either inside a tube or set of tubes, or perpendicular to a tube bank. You can also specify an empirical, generic configuration.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, use the **Tube bank grid arrangement** parameter to define the tube bank alignment of the other fluid as either Inline or Staggered. The red, downward-pointing arrow in the figure below indicates the direction of the fluid flowing external to the tube bank. The Inline figure also shows the **Number of tube rows along flow direction** and the **Number of tube segments in each tube row** parameters. Here, *flow direction* refers to the fluid of the respective dialog tab, and *tube* refers to the tubing of the other fluid. The **Length of each tube segment in a tube row** parameter is indicated in the Staggered figure.

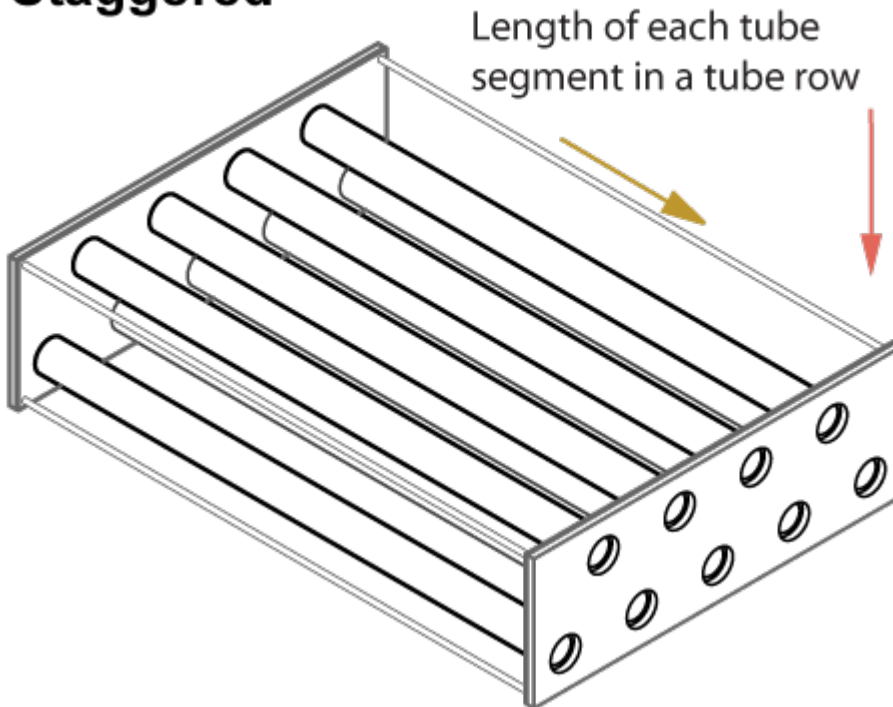


Number of tube segments  
in each tube row

### Inline



### Staggered



Only one fluid can have **Flow geometry** set to Flow perpendicular to bank of circular tubes at a time. The other fluid must be configured to either Flow inside one or more tubes or Generic. If **Flow geometry** for both fluids is set to Flow perpendicular to bank of circular tubes, you will receive an error.

### Fins

The heat exchanger configuration is without fins when the **Total fin surface area** parameter is set to 0 m<sup>2</sup>. Fins introduce additional surface area for additional heat transfer. Each fluid side has a separate fin area.

### Effectiveness-NTU Heat Transfer

The heat transfer rate is calculated over the averaged properties of both fluids.

The heat transfer is calculated as:

$$Q = \epsilon C_{\text{Min}}(T_{\text{In,TL}} - T_{\text{In,MA}}),$$

where:

- $C_{\text{Min}}$  is the lesser of the heat capacity rates of the two fluids. The heat capacity rate is the product of the fluid specific heat,  $c_p$ , and the fluid mass flow rate.  $C_{\text{Min}}$  is always positive.
- $T_{\text{In,TL}}$  is the inlet temperature of the thermal liquid.
- $T_{\text{In,MA}}$  is the inlet temperature of the moist air.
- $\epsilon$  is the heat exchanger effectiveness.

Effectiveness is a function of the heat capacity rate and the number of transfer units,  $NTU$ , and also varies based on the heat exchanger flow arrangement, which is discussed in more detail in "Effectiveness by Flow Arrangement" on page 1-1085. The  $NTU$  is calculated as:

$$NTU = \frac{1}{C_{\text{Min}}R},$$

where  $R$  is the total thermal resistance between the two flows, due to convection, conduction, and any fouling on the tube walls:

$$R = \frac{1}{U_{\text{TL}}A_{\text{Th,TL}}} + \frac{F_{\text{TL}}}{A_{\text{Th,TL}}} + R_{\text{W}} + \frac{F_{\text{MA}}}{A_{\text{Th,MA}}} + \frac{1}{U_{\text{MA}}A_{\text{Th,MA}}},$$

and where:

- $U$  is the convective heat transfer coefficient of the respective fluid. This coefficient is discussed in more detail in "Heat Transfer Coefficients" on page 1-1086.
- $F$  is the **Fouling factor** on the thermal liquid or moist air side, respectively.
- $R_{\text{W}}$  is the **Thermal resistance through heat transfer surface**.
- $A_{\text{Th}}$  is the heat transfer surface area of the respective side of the exchanger.  $A_{\text{Th}}$  is the sum of the wall surface area,  $A_{\text{W}}$ , and the **Total fin surface area**,  $A_{\text{F}}$ :

$$A_{\text{Th}} = A_{\text{W}} + \eta_{\text{F}}A_{\text{F}},$$

where  $\eta_{\text{F}}$  is the **Fin efficiency**.

### Effectiveness by Flow Arrangement

The heat exchanger effectiveness varies according to its flow configuration and the mixing in each fluid.

- When **Flow arrangement** is set to Parallel flow:

$$\epsilon = \frac{1 - \exp[-NTU(1 + C_R)]}{1 + C_R}$$

- When **Flow arrangement** is set to Counter flow:

$$\epsilon = \frac{1 - \exp[-NTU(1 - C_R)]}{1 - C_R \exp[-NTU(1 - C_R)]}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids unmixed:

$$\epsilon = 1 - \exp\left\{\frac{NTU^{0.22}}{C_R} \left[\exp(-C_R NTU^{0.78}) - 1\right]\right\}$$

- When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to Both fluids mixed:

$$\epsilon = \left[ \frac{1}{1 - \exp(-NTU)} + \frac{C_R}{1 - \exp(-C_R NTU)} - \frac{1}{NTU} \right]^{-1}$$

When one fluid is mixed and the other unmixed, the equation for effectiveness depends on the relative heat capacity rates of the fluids. When **Flow arrangement** is set to Cross flow and **Cross flow arrangement** is set to either Thermal Liquid 1 mixed & Moist Air 2 unmixed or Thermal Liquid 1 unmixed & Moist Air 2 mixed:

- When the fluid with  $C_{\max}$  is mixed and the fluid with  $C_{\min}$  is unmixed:

$$\epsilon = \frac{1}{C_R} (1 - \exp\{-C_R [1 - \exp(-NTU)]\})$$

- When the fluid with  $C_{\min}$  is mixed and the fluid with  $C_{\max}$  is unmixed:

$$\epsilon = 1 - \exp\left\{-\frac{1}{C_R} [1 - \exp(-C_R NTU)]\right\}$$

$C_R$  denotes the ratio between the heat capacity rates of the two fluids:

$$C_R = \frac{C_{\min}}{C_{\max}}$$

### Condensation

On the moist air side, a layer of condensation may form on the heat transfer surface. This liquid layer can influence the amount of heat transferred between the moist air and thermal liquid. The equations for E-NTU heat transfer above are given for *dry* heat transfer. To correct for the influence of condensation, the E-NTU equations are additionally calculated with the wet parameters listed below. Whichever of the two calculated heat flow rates results in a larger amount of moist air side cooling is used in heat calculations for each zone [1]. To use this method, the Lewis number is assumed to be close to 1 [1], which is true for moist air.

**E-NTU Quantities Used for Heat Transfer Rate Calculations**

	Dry calculation	Wet calculation
Moist air zone inlet temperature	$T_{in,MA}$	$T_{in,wb,MA}$
Heat capacity rate	$\bar{m}_{MA}\bar{c}_{p,MA}$	$\bar{m}_{MA}\bar{c}_{eq,MA}$
Heat transfer coefficient	$U_{MA}$	$U_{MA}\frac{\bar{c}_{eq,MA}}{\bar{c}_{p,MA}}$

where:

- $T_{in,MA}$  is the moist air inlet temperature.
- $T_{in,wb,MA}$  is the moist air wet-bulb temperature associated with  $T_{in,MA}$ .
- $\bar{m}_{MA}$  is the dry air mass flow rate.
- $\bar{c}_{p,MA}$  is the moist air heat capacity per unit mass of dry air.
- $\bar{c}_{eq,MA}$  is the equivalent heat capacity. The *equivalent heat capacity* is the change in the moist air specific enthalpy (per unit of dry air),  $\bar{h}_{MA}$ , with respect to temperature at saturated moist air conditions:

$$\bar{c}_{eq,MA} = \left( \frac{\partial \bar{h}_{MA}}{\partial T_{MA}} \right)_s.$$

The mass flow rate of the condensed water vapor leaving the moist air mass flow depends on the relative humidity between the moist air inlet and the channel wall and the heat exchanger NTUs:

$$\dot{m}_{cond} = -\bar{m}_{MA}(W_{wall,MA} - W_{in,MA})(1 - e^{-NTU_{MA}}),$$

where:

- $W_{wall,MA}$  is the humidity ratio at the heat transfer surface.
- $W_{in,MA}$  is the humidity ratio at the moist air flow inlet.
- $NTU_{MA}$  is the number of transfer units on the moist air side, calculated as:

$$NTU_{MA} = \frac{U_{MA}\frac{\bar{c}_{eq,MA}}{\bar{c}_{p,MA}}A_{Th,MA}}{\bar{m}_{MA}\bar{c}_{eq,MA}}.$$

The energy flow associated with water vapor condensation is based on the difference between the vapor specific enthalpy,  $h_{water,wall}$ , and the specific enthalpy of vaporization,  $h_{fg}$ , for water:

$$\phi_{Cond} = \dot{m}_{cond}(h_{water,wall} - h_{fg}).$$

The condensate is assumed to not accumulate on the heat transfer surface, and does not influence geometric parameters such as tube diameter.

**Heat Transfer Coefficients**

The equations below apply to both the thermal liquid and moist air sides and use the respective fluid properties.

### Flow Inside Tubes

The convective heat transfer coefficient varies according to the fluid Nusselt number:

$$U = \frac{Nu k}{D_H},$$

where:

- $Nu$  is the mean Nusselt number, which depends on the flow regime.
- $k$  is the fluid thermal conductivity.
- $D_H$  is tube hydraulic diameter.

For turbulent flows, the Nusselt number is calculated with the Gnielinski correlation:

$$Nu = \frac{\frac{fD}{8}(Re - 1000)Pr}{1 + 12.7\sqrt{\frac{f}{8}}(Pr^{2/3} - 1)},$$

where:

- $Re$  is the fluid Reynolds number.
- $Pr$  is the fluid Prandtl number.

For laminar flows, the Nusselt number is set by the **Laminar flow Nusselt number** parameter.

For transitional flows, the Nusselt number is a blend between the laminar and turbulent Nusselt numbers.

### Flow Across a Tube Bank

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, the Nusselt number is calculated based on the Hagen number,  $Hg$ , and depends on the **Tube bank grid arrangement** setting:

$$Nu = \begin{cases} 0.404Lq^{1/3} \left( \frac{Re+1}{Re+1000} \right)^{0.1}, & \text{Inline} \\ 0.404Lq^{1/3}, & \text{Staggered} \end{cases}$$

where:

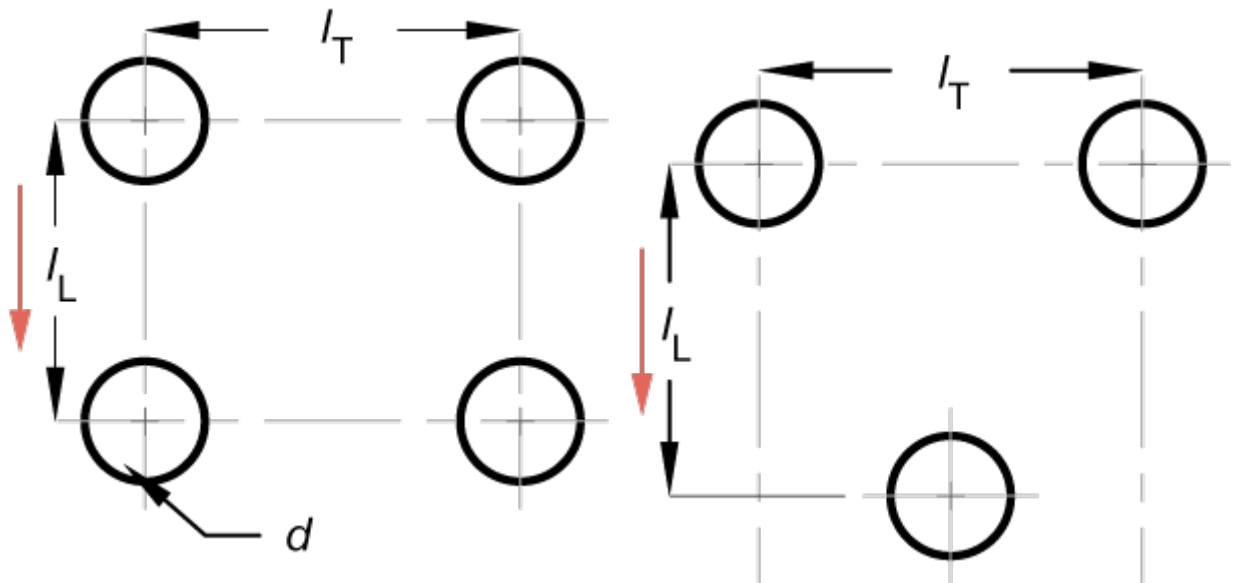
$$Lq = \begin{cases} 1.18Pr \left( \frac{4l_T/\pi - D}{l_L} \right) Hg(Re), & \text{Inline} \\ 0.92Pr \left( \frac{4l_T/\pi - D}{l_D} \right) Hg(Re), & \text{Staggered with } l_L \geq D \\ 0.92Pr \left( \frac{4l_T l_L/\pi - D^2}{l_L l_D} \right) Hg(Re), & \text{Staggered with } l_L < D \end{cases}$$

- $D$  is the **Tube outer diameter**.
- $l_L$  is the **Longitudinal tube pitch (along flow direction)**, the distance between the tube centers along the flow direction. *Flow direction* is the direction of flow of the external fluid.

- $l_T$  is the **Transverse tube pitch (perpendicular to flow direction)**, the distance between the centers of the tubing in one row of the other fluid.
- $l_D$  is the diagonal tube spacing, calculated as  $l_D = \sqrt{\left(\frac{l_T}{2}\right)^2 + l_L^2}$ .

For more information on calculating the Hagen number, see [6].

The measurements  $l_L$  and  $l_T$  are shown in the tube bank cross-section below. These distances are the same for both grid bank arrangement types.



### Cross-section of Tubing with Pitch Measurements

#### Empirical Nusselt Number Formulation

When the **Heat transfer coefficient model** parameter is set to Colburn equation or when **Flow geometry** is set to Generic, the Nusselt number is calculated by the empirical the Colburn equation:

$$\text{Nu} = a\text{Re}^b\text{Pr}^c,$$

where  $a$ ,  $b$ , and  $c$  are defined in the **Coefficients [a, b, c] for  $a\text{Re}^b\text{Pr}^c$**  parameter.

#### Pressure Loss

The equations below apply to both the thermal liquid and moist air sides and use the respective fluid properties.

#### Flows Inside Tubes

The pressure loss due to viscous friction varies depending on flow regime and configuration.

For turbulent flows, when the Reynolds number is above the **Turbulent flow lower Reynolds number limit**, and when **Pressure loss model** is set to Correlations for flow inside tubes, the pressure loss due to friction is calculated in terms of the Darcy friction factor.

For the thermal liquid side, the pressure differential between a port **A1** and the internal node I1 is:

$$p_{A1} - p_{I1} = \frac{f_{D,A} \dot{m}_{A1} |\dot{m}_{A1}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where:

- $\dot{m}_{A1}$  is the total flow rate through port **A1**.
- $f_{D,A}$  is the Darcy friction factor, according to the Haaland correlation:

$$f_{D,A1} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{Re_{A1}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2},$$

where  $\epsilon_R$  is the thermal liquid pipe **Internal surface absolute roughness**. Note that the friction factor is dependent on the Reynolds number, and is calculated at both ports for each liquid.

- $L$  is the **Total length of each tube** on the thermal liquid side.
- $L_{Add}$  is the thermal liquid side **Aggregate equivalent length of local resistances**, which is the equivalent length of a tube that introduces the same amount of loss as the sum of the losses due to other local resistances in the tube.
- $A_{CS}$  is the total tube cross-sectional area.

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{f_{D,B} \dot{m}_{B1} |\dot{m}_{B1}|}{2\rho D_H A_{CS}^2} \left( \frac{L + L_{Add}}{2} \right),$$

where  $\dot{m}_{B1}$  is the total flow rate through port **B1**.

The Darcy friction factor at port **B1** is:

$$f_{D,B1} = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{Re_{B1}} + \left( \frac{\epsilon_R}{3.7 D_H} \right)^{1.11} \right] \right\}^{-2}.$$

For laminar flows, when the Reynolds number is below the **Laminar flow upper Reynolds number limit**, and when **Pressure loss model** is set to **Correlations for flow inside tubes**, the pressure loss due to friction is calculated in terms of the **Laminar friction constant for Darcy friction factor**,  $\lambda$ .  $\lambda$  is a user-defined parameter when **Tube cross-section** is set to **Generic**, otherwise, the value is calculated internally.

The pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{\lambda \mu \dot{m}_{A1}}{2\rho D_H^2 A_{CS}} \left( \frac{L + L_{Add}}{2} \right),$$

where  $\mu$  is the fluid dynamic viscosity. The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{\lambda \mu \dot{m}_{B1}}{2\rho D_H^2 A_{CS}} \left( \frac{L + L_{Add}}{2} \right).$$

For transitional flows, when **Pressure loss model** is set to **Correlations for flow inside tubes**, the pressure differential due to viscous friction is a smoothed blend between the values for laminar and turbulent pressure losses.

#### Empirical Formulation for Flows Inside Tubes

When **Pressure loss model** is set to **Pressure loss coefficient** or when **Flow geometry** is set to **Generic**, the pressure losses due to viscous friction are calculated with an empirical pressure loss coefficient,  $\xi$ . The same equations apply to both the moist air and thermal liquid sides and use the respective fluid properties.

For the thermal liquid side, the pressure differential between port **A1** and internal node I1 is:

$$p_{A1} - p_{I1} = \frac{1}{2} \xi \frac{\dot{m}_{A1} |\dot{m}_{A1}|}{2\rho A_{CS}^2}.$$

The pressure differential between port **B1** and internal node I1 is:

$$p_{B1} - p_{I1} = \frac{1}{2} \xi \frac{\dot{m}_{B1} |\dot{m}_{B1}|}{2\rho A_{CS}^2}.$$

#### Pressure Loss for Flow Across Tube Banks

When **Flow geometry** is set to **Flow perpendicular to bank of circular tubes**, the Hagen number is used to calculate the pressure loss due to viscous friction. The same equations apply to both the moist air and thermal liquid sides and use the respective fluid properties.

For the moist air side, the pressure differential between port **A2** and internal node I2 is:

$$p_{A2} - p_{I2} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}),$$

where:

- $\mu$  is the moist air fluid dynamic viscosity.
- $N_R$  is the **Number of tube rows along flow direction**. When moist air is flowing external to a tube bank, this is the number of thermal liquid tube rows along the direction of the moist air flow.

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{1}{2} \frac{\mu^2 N_R}{\rho D^2} \text{Hg}(\text{Re}).$$

#### Empirical Formulation for Flows Across Tubes

When the **Pressure loss model** is set to **Euler number per tube row** or when **Flow geometry** is set to **Generic**, the pressure loss due to viscous friction is calculated with a pressure loss coefficient, in terms of the Euler number,  $Eu$ :

$$Eu = \frac{\xi}{N_R},$$

where  $\xi$  is the empirical pressure loss coefficient.

The pressure differential between port **A2** and internal node I2 is:



$$p_{A2} - p_{I2} = \frac{1}{2} N_R E u \frac{\dot{m}_{A2} |\dot{m}_{A2}|}{2\rho A_{CS}^2}.$$

The pressure differential between port **B2** and internal node I2 is:

$$p_{B2} - p_{I2} = \frac{1}{2} N_R E u \frac{\dot{m}_{B2} |\dot{m}_{B2}|}{2\rho A_{CS}^2}.$$

## Conservation Equations

### Thermal Liquid

The total mass accumulation rate in the thermal liquid is defined as:

$$\frac{dM_{TL}}{dt} = \dot{m}_{A1} + \dot{m}_{B1},$$

where:

- $M_{TL}$  is the total mass of the thermal liquid.
- $\dot{m}_{A1}$  is the mass flow rate of the fluid at port **A1**.
- $\dot{m}_{B1}$  is the mass flow rate of the fluid at port **B1**.

The flow is positive when flowing into the block through the port.

The energy conservation equation relates the change in specific internal energy to the heat transfer by the fluid:

$$M_{TL} \frac{du_{TL}}{dt} + u_{TL}(\dot{m}_{A1} + \dot{m}_{B1}) = \phi_{A1} + \phi_{B1} - Q,$$

where:

- $u_{TL}$  is the thermal liquid specific internal energy.
- $\phi_{A1}$  is the energy flow rate at port **A1**.
- $\phi_{B1}$  is the energy flow rate at port **B1**.
- $Q$  is heat transfer rate, which is positive when leaving the thermal liquid volume.

### Moist Air

There are three equations for mass conservation on the moist air side: one for the moist air mixture, one for condensed water vapor, and one for the trace gas.

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**Note** If **Trace gas model** is set to **None** in the Moist Air Properties (MA) block, the trace gas is not modeled in blocks in the moist air network. In the Heat Exchanger (TL-MA) block, this means that the conservation equation for trace gas is set to 0.

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The moist air mixture mass accumulation rate accounts for the changes of the entire moist air mass flow through the exchanger ports and the condensation mass flow rate:

$$\frac{dM_{MA}}{dt} = \dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{\text{Cond}}.$$

The mass conservation equation for water vapor accounts for the water vapor transit through the moist air side and condensation formation:

$$\frac{dx_w}{dt}M_{MA} + x_w(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{Cond}) = \dot{m}_{w,A2} + \dot{m}_{w,B2} - \dot{m}_{Cond},$$

where:

- $x_w$  is the mass fraction of the vapor.  $\frac{dx_w}{dt}$  is the rate of change of this fraction.
- $\dot{m}_{w,A2}$  is the water vapor mass flow rate at port **A2**.
- $\dot{m}_{w,B2}$  is the water vapor mass flow rate at port **B2**.
- $\dot{m}_{Cond}$  is the rate of condensation.

The trace gas mass balance is:

$$\frac{dx_g}{dt}M_{MA} + x_g(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{Cond}) = \dot{m}_{g,A2} + \dot{m}_{g,B2},$$

where:

- $x_g$  is the mass fraction of the trace gas.  $\frac{dx_g}{dt}$  is the rate of change of this fraction.
- $\dot{m}_{g,A2}$  is the trace gas mass flow rate at port **A2**.
- $\dot{m}_{g,B2}$  is the trace gas mass flow rate at port **B2**.

Energy conservation on the moist air side accounts for the change in specific internal energy due to heat transfer and water vapor condensing out of the moist air mass:

$$M_{MA} \frac{du_{MA}}{dt} + u_{MA}(\dot{m}_{A2} + \dot{m}_{B2} - \dot{m}_{Cond}) = \phi_{A2} + \phi_{B2} + Q - \phi_{Cond}.$$

where:

- $\phi_{A2}$  is the energy flow rate at port **A2**.
- $\phi_{B2}$  is the energy flow rate at port **B2**.
- $\phi_{Cond}$  is the energy flow rate due to condensation.

The heat transferred to or from the moist air,  $Q$ , is equal to the heat transferred from or to the thermal liquid.

## Ports

### Conserving

#### A1 — Thermal liquid port

thermal liquid

Inlet or outlet port associated with the thermal liquid.

#### B1 — Thermal liquid port

thermal liquid

Inlet or outlet port associated with the thermal liquid.

### **A2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

### **B2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

## **Output**

### **W — Moist air condensation rate**

physical signal

Water condensation rate in the moist air flow. The condensate does not accumulate on the heat transfer surface.

## **Parameters**

### **Configuration**

#### **Flow arrangement — Flow path alignment**

Cross flow (default) | Parallel flow | Counter flow

Flow path alignment between heat exchanger sides. The available flow arrangements are:

- **Parallel flow.** The flows run in the same direction.
- **Counter flow.** The flows run parallel to each other, in the opposite directions.
- **Cross flow.** The flows run perpendicular to each other.

#### **Cross flow arrangement — Thermal mixing condition in each of the flow channels**

Thermal Liquid 1 unmixed & Moist Air 2 mixed (default) | Both fluids unmixed |  
Thermal Liquid 1 mixed & Moist Air 2 unmixed | Both fluids mixed

Select whether each of the fluids can mix in its channel. Mixed flow means that the fluid is free to move in the transverse direction as it travels along the flow path. Unmixed flow means that the fluid is restricted to travel only along the flow path. For example, a side with fins is considered an unmixed flow.

### **Dependencies**

To enable this parameter, set **Flow arrangement** to **Cross flow**.

#### **Thermal resistance through heat transfer surface — Wall thermal resistance**

0 K/kW (default) | positive scalar

Thermal resistance of the wall separating the two sides of the heat exchanger. The wall thermal resistance, wall fouling, and the fluid convective heat transfer coefficient influence the amount of heat transferred between the flows.

#### **Cross-sectional area at port A1 — Flow area at port A1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **A1**.

**Cross-sectional area at port B1 — Flow area at port B1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **B1**.

**Cross-sectional area at port A2 — Flow area at port A2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air port **A2**.

**Cross-sectional area at port B2 — Area normal to flow at port B2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air port **B2**.

**Thermal Liquid 1**

**Flow geometry — Thermal liquid flow configuration**

Flow inside one or more tubes (default) | Flow perpendicular to bank of circular tubes | Generic

Thermal liquid flow path. The flow can run externally over a set of tubes or internal to a tube or set of tubes. You can also specify a generic parameterization based on empirical values.

**Number of tubes — Number of thermal liquid tubes**

25 (default) | positive scalar

Number of thermal liquid tubes. More tubes result in higher pressure losses due to viscous friction, but a larger amount of surface area for heat transfer.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Total length of each tube — Total length of each thermal liquid tube**

1 m (default) | positive scalar

Total length of each thermal liquid tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube cross section — Cross-sectional shape of a tube**

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of one tube. Set to Generic to specify an arbitrary cross-sectional geometry.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube inner diameter — Internal diameter of a single tube**

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Circular.

#### Tube width — Internal width of a single tube

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Rectangular.

#### Tube height — Internal height of a single tube

0.05 m (default) | positive scalar

Internal height of one tube cross-section. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Rectangular.

#### Annulus inner diameter (heat transfer surface) — Smaller diameter of annular cross-section

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

#### Dependencies

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Annular.

#### Annulus outer diameter — Larger diameter of annular cross-section

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

#### Dependencies

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Annular.

#### Cross-sectional area per tube — Internal flow area in each tube

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss — Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Perimeter of tube cross-section for heat transfer — Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Pressure loss model — Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Euler number per tube row | Pressure loss coefficient | Correlation for flow over tube bank

Method of pressure loss calculation due to viscous friction. Different models are available for different flow configurations. The settings are:

- Correlation for flow inside tubes. Use this setting to calculate the pressure loss with the Haaland correlation.
- Pressure loss coefficient. Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- Euler number per tube row. Use this setting to calculate the pressure loss based on an empirical Euler number.
- Correlation for flow over tube bank. Use this setting to calculate the pressure loss based on the Hagen number.

The pressure loss models available depend on the **Flow geometry** setting.

**Dependencies**

When **Flow geometry** is set to Flow inside one or more tubes, **Pressure loss model** can be set to either:

- Pressure loss coefficient.
- Correlation for flow inside tubes.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, **Pressure loss model** can be set to either:

- Correlation for flow over tube bank.
- Euler number per tube row.

When **Flow geometry** is set to Generic, the **Pressure loss model** parameter is disabled. Pressure loss is calculated empirically with the **Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$**  parameter.

### **Pressure loss coefficient, $\Delta p / (0.5 \cdot \rho \cdot v^2)$ – Empirical loss coefficient for all pressure losses in the channel**

10 (default) | positive scalar

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. It is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2} \rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the thermal liquid density, and  $v$  is the flow velocity.

#### **Dependencies**

To enable this parameter, set either:

- **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Pressure loss coefficient.
- **Flow geometry** to Generic.

### **Aggregate equivalent length of local resistances – Combined length of all local resistances per tube**

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

#### **Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlations for flow inside tubes.

### **Internal surface absolute roughness – Mean surface roughness height**

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and either:

- **Pressure loss model**
- **Heat transfer coefficient model**

to Correlation for flow inside tubes.

**Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow**

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number limit**, the flow regime is transitional.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and either:

- **Pressure loss model**
- **Heat transfer model**

to Correlation for flow inside tubes.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional between the laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter is also known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Correlation for flow inside tubes, **Tube cross section** to Generic, and **Pressure loss model** to Correlation for flow inside tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow over tube bank (default) | Colburn equation | Correlation for flow inside tubes

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:



- **Colburn equation.** Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$  of the Colburn equation.
- **Correlation for flow over tube bank.** Use this setting to calculate the heat transfer coefficient based on the tube bank correlation using the Hagen number.
- **Correlation for flow inside tubes.** Use this setting to calculate the heat transfer coefficient for pipe flows with the Gnielinski correlation.

#### Dependencies

To enable this parameter, set **Flow geometry** to either:

- Flow perpendicular to bank of circular tubes.
- Flow inside one or more tubes.

#### Coefficients [a, b, c] for $a \cdot Re^b \cdot Pr^c$ – Colburn equation coefficients

[0.023, 0.8, 0.33] (default) | three-element vector

Three-element vector containing the empirical coefficients of the Colburn equation. The Colburn equation is a formulation for calculating the Nusselt Number. The general form of the Colburn equation is:

$$Nu = aRe^bPr^c.$$

When the **Heat transfer coefficient model** is set to **Colburn equation** and **Flow geometry** is set to **Flow inside one or more tubes**, or **Flow geometry** is set to **Generic**, the default Colburn equation is:

$$Nu = 0.023Re^{0.8}Pr^{1/3}.$$

When the **Heat transfer coefficient model** is set to **Colburn equation** and **Flow geometry** is set to **Flow perpendicular to bank of circular tubes**, the default Colburn equation is:

$$Nu = 0.27Re^{0.63}Pr^{0.36}.$$

#### Dependencies

To enable this parameter, set:

##### 1 **Flow geometry** to either:

- Flow inside one or more tubes
- Flow perpendicular to bank of circular tubes

and **Heat transfer coefficient model** to **Colburn equation**.

##### 2 **Flow geometry** to **Generic**.

#### Laminar flow Nusselt number – Ratio of convective to conductive heat transfer in the laminar flow regime

3.66 (default) | positive scalar

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes, **Tube cross-section** to Generic, and **Heat transfer parameterization** to Correlation for flow inside tubes.

**Tube bank grid arrangement — Geometrical placement of tube rows in the bank**

Inline (default) | Staggered

Alignment of tubes in a tube bank. Rows are either in line with their neighbors, or staggered.

- **Inline:** All tube rows are located directly behind each other.
- **Staggered:** Tubes of the one tube row are located at the gap between tubes of the previous tube row.

Tube alignment influences the Nusselt number and the heat transfer rate.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Number of tube rows along flow direction — Number of moist air tube rows in the tube bank**

5 (default) | positive scalar

Number of moist air tube rows in a tube bank. The rows are aligned with the direction of thermal liquid flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Number of tube segments in each tube row — Number of moist air tubes in each row of the tube bank**

5 (default) | positive scalar

Number of moist air tubes in each row of a tube bank. This measurement is perpendicular to the thermal liquid flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Length of each tube segment in a tube row — Length of each moist air tube**

1 m (default) | positive scalar

Length of each moist air tube that spans a tube row. All tubes in a tube bank are the same length.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Tube outer diameter – Outer diameter of a moist air tube**

0.05 m (default) | positive scalar

Outer diameter of a moist air tube. The cross-section is uniform along a tube and so the diameter is constant throughout. This value influences the losses in the flow across a tube bank due to viscous friction.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Longitudinal tube pitch (along flow direction) – Center-to-center distance between moist air tube rows**

0.15 m (default) | positive scalar

Distance between tube centers of the moist air tube bank aligned with the direction of flow of the thermal liquid.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Transverse tube pitch (perpendicular to flow direction) – Center-to-center distance between moist air fluid tubes in a row**

0.15 (default) | positive scalar

Distance between the tube centers in a row of moist air tubes. This measurement is perpendicular to the thermal liquid flow direction. See “Heat Transfer Coefficients” on page 1-1086 for more information.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Euler number per tube row,  $\Delta p / (N \cdot 0.5 \cdot \rho \cdot v^2)$  – Euler number for each row of the tube bank**

10 (default) | positive scalar

Empirical coefficient for pressure drop across one tube row. The Euler number is the ratio between pressure drop and fluid momentum:

$$Eu = \frac{\Delta p}{N \frac{1}{2} \rho v^2},$$

where  $N$  is the **Number of tube rows along flow direction**,  $\Delta p$  is the pressure drop,  $\rho$  is the thermal liquid density, and  $v$  is the flow velocity.

Each tube row is located in a plane perpendicular to the thermal liquid flow.

**Dependencies**

To enable this parameter, set either:

- **Flow geometry** to Flow perpendicular to bank of circular tubes and **Pressure loss model** to Euler number per tube row.
- **Flow geometry** to Generic.

**Minimum free-flow area — Smallest total flow area between inlet and outlet**

0.01 m<sup>2</sup> (default) | positive scalar

Smallest total flow area between inlet and outlet. If the channel is a collection of ducts, tubes, slots, or grooves, the minimum free-flow area is the sum of the smallest areas.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Heat transfer surface area without fins — Total area of the heat transfer surface excluding fins**

2 m<sup>2</sup> (default) | positive scalar

Total area of the heat transfer surface, excluding fins.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Thermal liquid volume inside heat exchanger — Total volume of thermal liquid in the heat exchanger**

0.05 m<sup>3</sup> (default) | positive scalar

Total volume of thermal liquid in the heat exchanger.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Fouling factor — Additional thermal resistance due to fouling deposits**

0.1 m<sup>2</sup>\*K/kW (default) | positive scalar

Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time. However, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area — Total heat transfer surface area of all fins**

0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency — Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial thermal liquid pressure — Moist air pressure at the start of simulation**

0.101325 MPa (default) | positive scalar

Thermal liquid pressure at the start of the simulation.

**Initial thermal liquid temperature — Temperature at the start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the thermal liquid channel at the start of the simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Moist Air 2****Flow geometry — Moist air flow configuration**

Flow perpendicular to bank of circular tubes (default) | Flow inside one or more tubes | Generic

Moist air flow path. The flow can run externally over a set of tubes or internal to a tube or set of tubes. You can also specify a generic parameterization based on empirical values.

**Number of tubes — Number of moist air tubes**

25 (default) | positive scalar

Number of moist air tubes. More tubes result in higher pressure losses due to viscous friction, but a larger amount of surface area for heat transfer.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Total length of each tube — Total length of each moist air tube**

1 m (default) | positive scalar

Total length of each moist air tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube cross section — Cross-sectional shape of a tube**

Circular (default) | Rectangular | Annular | Generic

Cross-sectional shape of one tube. Set to Generic to specify an arbitrary cross-sectional geometry.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes.

**Tube inner diameter — Internal diameter of a single tube**

0.05 m (default) | positive scalar

Internal diameter of the cross-section of one tube. The cross-section and diameter are uniform along the tube. The size of the diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Circular.

**Tube width — Internal width of a single tube**

0.05 m (default) | positive scalar

Internal width of the cross-section of one tube. The cross-section and width are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Tube height — Internal height of a single tube**

0.05 m (default) | positive scalar

Internal height of one tube cross-section. The cross-section and height are uniform along the tube. The width and height influence the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Rectangular.

**Annulus inner diameter (heat transfer surface) — Smaller diameter of annular cross-section**

0.05 m (default) | positive scalar

Smaller diameter of the annular cross-section of one tube. The cross-section and inner diameter are uniform along the tube. The inner diameter influences the pressure loss and heat transfer calculations. Heat transfer occurs through the inner surface of the annulus.

**Dependencies**

To enable this parameter, set **Flow geometry** parameterization of Flow inside one or more tubes and **Tube cross-section** to Annular.

**Annulus outer diameter — Larger diameter of annular cross-section**

0.1 m (default) | positive scalar

Larger diameter of the annular cross-section of one tube. The cross-section and outer diameter are uniform along the tube. The outer diameter influences the pressure loss and heat transfer calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Annular.

**Cross-sectional area per tube — Internal flow area in each tube**

0.002 m<sup>2</sup> (default) | positive scalar

Internal flow area of each tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Wetted perimeter of tube cross-section for pressure loss — Perimeter of tube cross-section that fluid touches**

0.15 m (default) | positive scalar

Perimeter of the tube cross-section that the fluid touches. The cross-section and perimeter are uniform along the tube. This value is applied in pressure loss calculations.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Perimeter of tube cross-section for heat transfer — Perimeter of a single tube for heat transfer calculations**

0.15 m (default) | positive scalar

Tube perimeter for heat transfer calculations. This is often the same as the tube perimeter, but in cases such as the annular cross-section, this may be only the inner or outer diameter, depending on the heat-transferring surface. The cross-section and tube perimeter are uniform along the tube.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Tube cross-section** to Generic.

**Pressure loss model — Method of pressure loss calculation due to viscous friction**

Correlation for flow inside tubes (default) | Euler number per tube row | Pressure loss coefficient | Correlation for flow over tube bank

Method of pressure loss calculation due to viscous friction. Different models are available for different flow configurations. The settings are:

- **Correlation for flow inside tubes.** Use this setting to calculate the pressure loss with the Haaland correlation.
- **Pressure loss coefficient.** Use this setting to calculate the pressure loss based on an empirical loss coefficient.
- **Euler number per tube row.** Use this setting to calculate the pressure loss based on an empirical Euler number.
- **Correlation for flow over tube bank.** Use this setting to calculate the pressure loss based on the Hagen number.

The pressure loss models available depend on the **Flow geometry** setting.

**Dependencies**

When **Flow geometry** is set to Flow inside one or more tubes, **Pressure loss model** can be set to either:

- **Pressure loss coefficient.**

- Correlation for flow inside tubes.

When **Flow geometry** is set to Flow perpendicular to bank of circular tubes, **Pressure loss model** can be set to either:

- Correlation for flow over tube bank.
- Euler number per tube row.

When **Flow geometry** is set to Generic, the **Pressure loss model** parameter is disabled. Pressure loss is calculated empirically with the **Pressure loss coefficient,  $\Delta p / (0.5 \cdot \rho \cdot v^2)$**  parameter.

### **Pressure loss coefficient, $\Delta p / (0.5 \cdot \rho \cdot v^2)$ – Empirical loss coefficient for all pressure losses in the channel**

10 (default) | positive scalar

Empirical loss coefficient for all pressure losses in the channel. This value accounts for wall friction and minor losses due to bends, elbows, and other geometry changes in the channel.

The loss coefficient can be calculated from a nominal operating condition or be tuned to fit experimental data. The coefficient is defined as:

$$\xi = \frac{\Delta p}{\frac{1}{2} \rho v^2},$$

where  $\Delta p$  is the pressure drop,  $\rho$  is the moist air density, and  $v$  is the flow velocity.

#### **Dependencies**

To enable this parameter, set either:

- **Flow geometry** to Generic.
- **Pressure loss model** to Pressure loss coefficient.

### **Aggregate equivalent length of local resistances – Combined length of all local resistances per tube**

0.1 m (default) | positive scalar

Combined length of all local resistances per tube. This value is the length of tubing that results in the same pressure losses as the sum of all minor losses in the tube due to resistances such as bends, tees, or unions. A longer combined length results in larger pressure losses. The block adds the value of this parameter to the **Total length of each tube** parameter in the calculations of pressure loss due to friction.

#### **Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlations for flow inside tubes.

### **Internal surface absolute roughness – Mean surface roughness height**

15e-6 m (default) | positive scalar

Mean height of tube surface defects. A rougher wall results in larger pressure losses in the turbulent regime for pressure loss calculated with the Haaland correlation.



**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and either:

- **Pressure loss model**
- **Heat transfer coefficient model**

to Correlation for flow inside tubes.

**Laminar flow upper Reynolds number limit – Largest Reynolds number that indicates laminar flow**

2000 (default) | positive scalar

Largest Reynolds number that indicates laminar flow. Between this value and the **Turbulent flow lower Reynolds number limit**, the flow regime is transitional.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Turbulent flow lower Reynolds number limit – Smallest Reynolds number that indicates turbulent flow**

4000 (default) | positive scalar

Smallest Reynolds number that indicates turbulent flow. Between this value and the **Laminar flow upper Reynolds number limit**, the flow regime is transitional between the laminar and turbulent regimes.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes and **Pressure loss model** to Correlation for flow inside tubes.

**Laminar friction constant for Darcy friction factor – Coefficient of pressure loss due to viscous friction in laminar flows**

64 (default) | positive scalar

Coefficient in pressure loss equations for viscous friction in laminar flows. This parameter is also known as the *shape factor*. The default value corresponds to a circular tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Correlation for flow inside tubes, **Tube cross section** to Generic, and **Pressure loss model** to Correlation for flow inside tubes.

**Heat transfer coefficient model – Method of calculating heat transfer coefficient between fluid and wall**

Correlation for flow over tube bank (default) | Colburn equation | Correlation for flow inside tubes

Method of calculating the heat transfer coefficient between the fluid and the wall. The available settings are:

- Colburn equation. Use this setting to calculate the heat transfer coefficient with user-defined variables  $a$ ,  $b$ , and  $c$  of the Colburn equation.

- Correlation for flow over tube bank. Use this setting to calculate the heat transfer coefficient based on the tube bank correlation using the Hagen number.
- Correlation for flow inside tubes. Use this setting to calculate the heat transfer coefficient for pipe flows with the Gnielinski correlation.

#### Dependencies

To enable this parameter, set **Flow geometry** to either:

- Flow perpendicular to bank of circular tubes .
- Flow inside one or more tubes.

#### Coefficients [a, b, c] for $a \cdot Re^b \cdot Pr^c$ — Colburn equation coefficients

[0.023, 0.8, 0.33] (default) | three-element vector

Three-element vector containing the empirical coefficients of the Colburn equation. The Colburn equation is a formulation for calculating the Nusselt Number. The general form of the Colburn equation is:

$$Nu = aRe^bPr^c.$$

When the **Heat transfer coefficient model** is set to Colburn equation and **Flow geometry** is set to Flow inside one or more tubes, or **Flow geometry** is set to Generic, the default Colburn equation is:

$$Nu = 0.023Re^{0.8}Pr^{1/3}.$$

When the **Heat transfer coefficient model** is set to Colburn equation and **Flow geometry** is set to Flow perpendicular to bank of circular tubes, the default Colburn equation is:

$$Nu = 0.27Re^{0.63}Pr^{0.36}.$$

#### Dependencies

To enable this parameter, set:

##### 1 **Flow geometry** to either:

- Flow inside one or more tubes
- Flow perpendicular to bank of circular tubes

and **Heat transfer coefficient model** to Colburn equation.

##### 2 **Flow geometry** to Generic.

#### Laminar flow Nusselt number — Ratio of convective to conductive heat transfer in the laminar flow regime

3.66 (default) | positive scalar

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate and depends on the tube cross-section.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow inside one or more tubes, **Tube cross-section** to Generic, and **Heat transfer parameterization** to Correlation for flow inside tubes.

**Tube bank grid arrangement — Geometrical placement of thermal liquid rows in the bank**

Inline (default) | Staggered

Alignment of tubes in a tube bank. Rows are either in line with their neighbors, or staggered.

- **Inline:** All tube rows are located directly behind each other.
- **Staggered:** Tubes of the one tube row are located at the gap between tubes of the previous tube row.

Tube alignment influences the Nusselt number and the heat transfer rate.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Number of tube rows along flow direction — Number of thermal liquid tube rows in the tube bank**

5 (default) | positive scalar

Number of thermal liquid fluid tube rows in a tube bank. The rows are aligned with the direction of moist air flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Number of tube segments in each tube row — Number of thermal liquid tubes in each row of the tube bank**

5 (default) | positive scalar

Number of thermal liquid tubes in each row of a tube bank. This measurement is perpendicular to the moist air flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Length of each tube segment in a tube row — Length of each thermal liquid tube**

1 m (default) | positive scalar

Length of each thermal liquid tube that spans a tube row. All tubes in a tube bank are the same length.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Tube outer diameter – Outer diameter of a single thermal liquid tube**

0.05 m (default) | positive scalar

Outer diameter of a thermal liquid tube. The cross-section is uniform along a tube and so the diameter is constant throughout. This value influences the losses in the flow across a tube bank due to viscous friction.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Longitudinal tube pitch (along flow direction) – Center-to-center distance between thermal liquid tube rows**

0.15 m (default) | positive scalar

Distance between tube centers of the thermal liquid tube bank, aligned with the direction of flow of the moist air.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Transverse tube pitch (perpendicular to flow direction) – Center-to-center distance between thermal liquid tubes in a row**

0.15 m (default) | positive scalar

Distance between the tube centers in a row of thermal liquid tubes. This measurement is perpendicular to the moist air flow direction. See “Heat Transfer Coefficients” on page 1-1086 for more information.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes.

**Euler number per tube row,  $\Delta p / (N * 0.5 * \rho * v^2)$  – Euler number for each row of the tube bank**

10 (default) | positive scalar

Empirical coefficient for pressure drop across one tube row. The Euler number is the ratio between pressure drop and fluid momentum:

$$Eu = \frac{\Delta p}{N \frac{1}{2} \rho v^2},$$

where  $N$  is the **Number of tube rows along flow direction**,  $\Delta p$  is the pressure drop,  $\rho$  is the moist air mixture density, and  $v$  is the flow velocity.

Each tube row is located in a plane perpendicular to the moist air flow.

**Dependencies**

To enable this parameter, set **Flow geometry** to Flow perpendicular to bank of circular tubes and **Pressure loss model** to Euler number per tube row.

**Minimum free-flow area — Smallest total flow area between inlet and outlet**0.01 m<sup>2</sup> (default) | positive scalar

Smallest total flow area between inlet and outlet. If the channel is a collection of ducts, tubes, slots, or grooves, the minimum free-flow area is the sum of the smallest areas.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Heat transfer surface area without fins — Total area of the heat transfer surface excluding fins**2 m<sup>2</sup> (default) | positive scalar

Total area of the heat transfer surface, excluding fins.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Moist air volume inside heat exchanger — Total volume of moist air in the heat exchanger**0.05 m<sup>3</sup> (default) | positive scalar

Total volume of moist air in the heat exchanger.

**Dependencies**

To enable this parameter, set **Flow geometry** to Generic.

**Fouling factor — Additional thermal resistance due to fouling deposits**0.1 m<sup>2</sup>\*K/kW (default) | positive scalar

Additional thermal resistance due to fouling layers on the surfaces of the wall. In real systems, fouling deposits grow over time. However, the growth is slow enough to be assumed constant during the simulation.

**Total fin surface area — Total heat transfer surface area of all fins**0 m<sup>2</sup> (default) | positive scalar

Total heat transfer surface area of both sides of all fins. For example, if the fin is rectangular, the surface area is double the area of the rectangle.

The total heat transfer surface area is the sum of the channel surface area and the effective fin surface area, which is the product of the **Fin efficiency** and the **Total fin surface area**.

**Fin efficiency — Ratio of actual-to-ideal transfer rates for fin**

0.5 (default) | positive scalar in the range [0,1]

Ratio of actual heat transfer to ideal heat transfer through the fins if the entire fin is at the primary heat transfer surface temperature.

**Initial moist air pressure — Moist air pressure at the start of simulation**

0.101325 MPa (default) | positive scalar

Moist air pressure at the start of the simulation.

**Initial moist air temperature – Temperature at the start of simulation**

293.15 K (default) | positive scalar | two-element vector

Temperature in the moist air fluid channel at the start of the simulation. This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial temperature in the channel. A vector value represents the initial temperature at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Initial moisture specification – Moisture specification**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Moisture specification, which can be set as relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

**Initial moist air relative humidity – Relative humidity at the start of simulation**

0.5 (default) | positive scalar in the range of [0,1] | two-element vector

Relative humidity in the moist air channel at the start of the simulation. The relative humidity is the ratio of the water vapor partial pressure to the water vapor saturation pressure, or the ratio of the water vapor mole fraction to the water vapor mole fraction at saturation.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial relative humidity in the channel. A vector value represents the initial relative humidity at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Relative humidity.

**Initial moist air specific humidity – Specific humidity at the start of simulation**

0.01 (default) | positive scalar in the range of [0,1] | two-element vector

Specific humidity in the moist air channel at the start of simulation. The specific humidity is the mass fraction of water vapor to the combined total mass of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial specific humidity in the channel. A vector value represents the initial specific humidity at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Specific humidity.

**Initial moist air water vapor mole fraction – Mole fraction of water vapor at the start of simulation**

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Mole fraction of the water vapor in the moist air channel at the start of simulation. The water vapor mole fraction is relative to the combined molar quantity of water vapor, trace species, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial vapor mole fraction in the channel. A vector value represents the initial vapor mole fraction at the

inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

#### Dependencies

To enable this parameter, set **Initial moisture specification** to Mole fraction.

#### Initial moist air humidity ratio — Humidity ratio at the start of simulation

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Humidity ratio in the moist air channel at the start of the simulation. The humidity ratio is the ratio of the mass of water vapor to the mass of dry air and trace gas.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean initial humidity ratio in the channel. A vector value represents the initial humidity ratio at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

#### Dependencies

To enable this parameter, set **Initial moisture specification** to Humidity ratio.

#### Initial trace gas specification — Measurement type of trace gas

Mass fraction (default) | Mole fraction

Measurement type of trace gas.

#### Initial moist air trace gas mass fraction — Amount of trace gas in the moist air channel

0.001 (default) | positive scalar in the range of [0,1] | two-element vector

Amount of trace gas in the moist air channel by mass fraction at the start of the simulation. The mass fraction is relative to the combined total mass of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean trace gas mass fraction in the channel. A vector value represents the initial trace gas mass fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

#### Dependencies

To enable this parameter, set **Initial trace gas specification** to Mass fraction.

#### Initial moist air trace gas mole fraction — Mole fraction of trace gas at the start of simulation

0.001 (default) | positive scalar in the range of [0,1] | two-element vector

Amount of trace gas in the moist air channel by mole fraction at the start of the simulation. The mole fraction is relative to the combined molar total of water vapor, trace gas, and dry air.

This parameter can be a scalar or a two-element vector. A scalar value represents the mean trace gas mole fraction in the channel. A vector value represents the initial trace gas mole fraction at the inlet and outlet in the form [inlet, outlet]. The block calculates a linear gradient between the two ports. The inlet and the outlet ports are identified according to the initial flow direction.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

### Dependencies

To enable this parameter, set **Initial trace gas specification** to Mole fraction.

### Relative humidity at saturation — Relative humidity point of condensation

1 (default) | positive scalar in the range of [0,1]

Relative humidity point of condensation. Condensation occurs above this value. A value greater than 1 indicates a supersaturated vapor.

## Version History

Introduced in R2020b

## References

- [1] *2013 ASHRAE Handbook - Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013.
- [2] Braun, J. E., S. A. Klein, and J. W. Mitchell. "Effectiveness Models for Cooling Towers and Cooling Coils." *ASHRAE Transactions* 95, no. 2, (June 1989): 164-174.
- [3] Çengel, Yunus A. *Heat and Mass Transfer: A Practical Approach*. 3rd ed, McGraw-Hill, 2007.
- [4] Ding, X., Eppe J.P., Lebrun, J., Wasacz, M. "Cooling Coil Model to be Used in Transient and/or Wet Regimes. Theoretical Analysis and Experimental Validation." *Proceedings of the Third International Conference on System Simulation in Buildings* (1990): 405-411.
- [5] Mitchell, John W., and James E. Braun. *Principles of Heating, Ventilation, and Air Conditioning in Buildings*. Wiley, 2013.
- [6] Shah, R. K., and Dušan P. Sekulić. *Fundamentals of Heat Exchanger Design*. John Wiley & Sons, 2003.
- [7] White, Frank M. *Fluid Mechanics*. 6th ed, McGraw-Hill, 2009.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Condenser Evaporator (TL-2P) | Condenser Evaporator (2P-MA) | E-NTU Heat Transfer | Heat Exchanger (G-TL) | Heat Exchanger (TL-TL)



# Isothermal Liquid Predefined Properties (IL)

Sets working fluid properties for an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Utilities



## Description

The Isothermal Liquid Predefined Properties (IL) block sets the working fluid liquid properties of your isothermal liquid network. The available predefined fluids are:

- “Water” on page 1-1115
- “Seawater” on page 1-1116
- “Ethylene-, Propylene-, and Glycerol-Water Mixtures” on page 1-1115
- “Aviation Fuel Jet-A” on page 1-1116
- “Diesel Fuel” on page 1-1116
- “SAE 5W-30” on page 1-1116

You can also model dissolved air in the system as a function of pressure. If you would like to specify your own working fluid properties, use the Foundation Library Isothermal Liquid Properties (IL) block. If you do not specify a fluid, the system defaults will apply. See “Specify Fluid Properties” for more details.

## Fluid Properties Range

### Water

Water properties are provided between the triple point, when the fluid temperature and pressure reach 273.160 K and 611.657 Pa, and the critical point, when the fluid temperature reaches 647.096 K.  $P_{\min}$  is set by the triple point or the saturation pressure, whichever is greater.

### Ethylene-, Propylene-, and Glycerol-Water Mixtures

The properties for ethylene-glycol, propylene-glycol, and glycerol are provided for temperatures above the solution freezing point. Note that the displayed minimum temperature when visualizing properties may be lower than the fluid freezing point; displayed temperatures are not updated for different mixture concentrations.

When specifying the mixture, you can define the concentration of ethylene glycol, propylene glycol, or glycerol to water by mass fraction or volume fraction in the **Concentration type** parameter.

Properties are available for concentration by mass between 0 and 0.6 and by volume between 0 and 1 for ethylene glycol; for concentration by mass between 0 and 0.6 and by volume between 0.1 and 0.6 for propylene glycol; and for concentration by mass between 0 and 0.6 for glycerol. Glycerol concentration by volume is not available.

The properties are stored as a function of temperature and concentration. All properties, except for density and the thermal expansion coefficient  $\alpha$  are maintained as constants for a range of pressures.

### **Seawater**

Seawater properties are provided for temperatures between 273.15 K and 393.15 K and for pressures above the system saturation pressure. The salinity concentration can range from 0 to 0.12 by mass.

The properties are stored as tabulated data with respect to pressure and temperature. The data is derived from MIT's Seawater software. For more information, see: <https://web.mit.edu/seawater/>

### **Aviation Fuel Jet-A**

The properties provided are for a general, representative fuel mixture based on Jet-A-4658 and Jet-A-3638 surrogates. The properties are provided at temperatures between 222.22 K and 645.61 K and pressures above the saturation point.

The properties are stored as tabulated data with respect to pressure and temperature.

### **Diesel Fuel**

Diesel properties are provided for temperatures between 238.20 K and 690.97 K and for pressures above the saturation point.

### **SAE 5W-30**

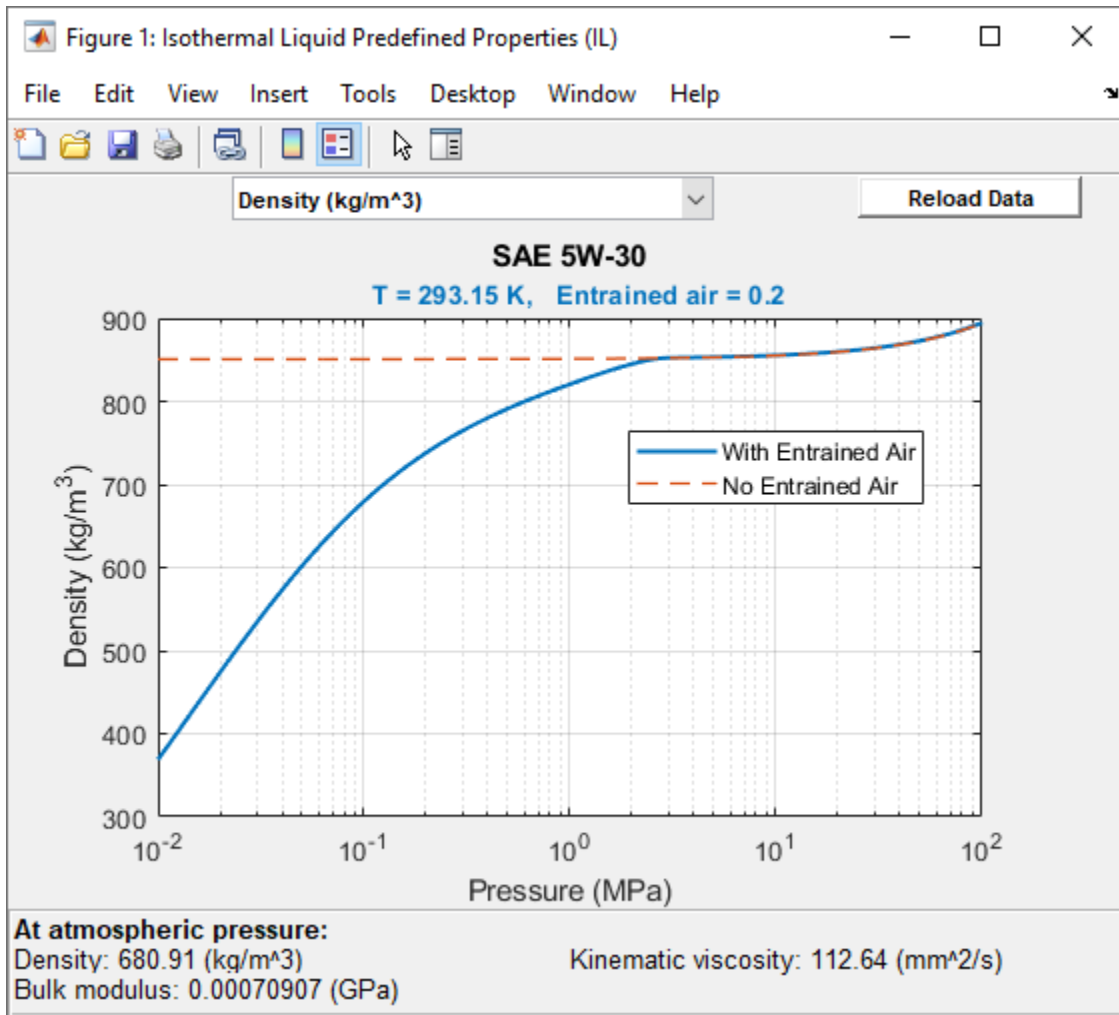
SAE 5W-30 properties are provided for temperatures between 235.15 K and 473.15 K and for pressures above 0.01 MPa.

### **Dissolved Air**

You can optionally model air dissolved into the liquid system. Setting **Air dissolution model** to On models dissolution between **Atmospheric pressure** and the **Pressure at which all entrained air is dissolved** by Henry's law. For more information, see "Fluid Models with Entrained Air".

### **Visualizing Fluid Properties**

To visualize the fluid density and bulk modulus in your network, right-click on the Isothermal Liquid Predefined Properties (IL) block and select **Fluids > Plot Fluid Properties**:



Use the **Reload Data** button to regenerate the plot whenever the fluid selection or fluid parameters change.

## Ports

### Conserving

#### A – Connection port

isothermal liquid

Isothermal liquid conserving port that connects the block to the network. This port connects to any point on an isothermal liquid connection line within a block diagram. When you connect the Isothermal Liquid Predefined Properties (IL) block to a network line, the liquid properties are propagated to all blocks in the circuit.

## Parameters

### Liquid

#### **Isothermal liquid – Fluid choice**

Water (default) | Seawater (MIT model) | Ethylene glycol and water mixture | Propylene glycol and water mixture | Glycerol and water mixture | Aviation fuel Jet-A | Diesel fuel | SAE 5W-30

Choice of working fluid in the system.

#### **Dissolved salt mass fraction (salinity) – Salt concentration**

3.5e-3 (default) | positive scalar between (0, 0.12]

Concentration of salt in water by mass.

#### **Dependencies**

To enable this parameter, set **Isothermal liquid** to Seawater (MIT).

#### **Concentration type – Concentration by mass or volume**

Volume fraction (default) | Mass fraction

Whether the solute is measured in water by mass or volume.

#### **Dependencies**

To enable this parameter, set **Isothermal liquid** to:

- Ethylene glycol and water mixture.
- Propylene glycol and water mixture.

#### **Ethylene glycol volume fraction – Ethylene glycol concentration by volume**

0.1 (default) | positive scalar between (0, 1.0]

Fraction of ethylene glycol in water, by volume.

#### **Dependencies**

To enable this parameter, set **Isothermal liquid** to Ethylene glycol and water mixture and **Concentration type** to Volume fraction.

#### **Ethylene glycol mass fraction – Ethylene glycol concentration by mass**

0.1 (default) | positive scalar between (0, 0.6]

Fraction of ethylene glycol in water, by mass.

#### **Dependencies**

To enable this parameter, set **Isothermal liquid** to Ethylene glycol and water mixture and **Concentration type** to Mass fraction.

#### **Isothermal bulk modulus at atmospheric pressure (no entrained air) – Bulk modulus**

2.1791 GPa (default) | positive scalar

Solution bulk modulus at atmospheric pressure.

**Dependencies**

To enable this parameter, set **Isothermal liquid** to:

- Ethylene glycol and water mixture.
- Propylene glycol and water mixture.
- Glycerol and water mixture.

**Minimum valid pressure — Lower pressure limit**

0.01 (default) | positive scalar

Lower pressure limit during simulations. The **Atmospheric pressure** must greater than or equal to the **Minimum valid pressure**.

**Dependencies**

To enable this parameter, set **Isothermal liquid** to:

- Ethylene glycol and water mixture.
- Propylene glycol and water mixture.
- Glycerol and water mixture.

**Propylene glycol volume fraction — Propylene glycol concentration by volume**

0.1 (default) | positive scalar between [0.1, 0.6]

Fraction of propylene glycol in water, by volume.

**Dependencies**

To enable this parameter, set **Isothermal liquid** to Propylene glycol and water mixture and **Concentration type** to Volume fraction.

**Propylene glycol mass fraction — Propylene glycol concentration by mass**

0.1 (default) | positive scalar between (0, 0.6]

Fraction of propylene glycol in water, by mass.

**Dependencies**

To enable this parameter, set **Isothermal liquid** to Propylene glycol and water mixture and **Concentration type** to Mass fraction.

**Glycerol mass fraction — Glycerol concentration by mass**

0.1 (default) | positive scalar between (0, 0.6]

Fraction of glycerol in water, by mass.

**Dependencies**

To enable this parameter, set **Isothermal liquid** to Glycerol and water mixture.

**System temperature — Network temperature**

300 K (default) | positive scalar

Isothermal liquid network temperature.

**Viscosity derating factor – Viscosity correction factor**

1 (default) | positive scalar

Correction factor for fluids diverging from the clean fluid standard viscosity.

**Atmospheric pressure – User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

Environmental pressure of the system.

**Entrained Air****Volumetric fraction of air that is entrained at atmospheric pressure – System air entrainment at atmospheric pressure**

0.005 (default) | positive scalar

Air entrainment in fluid network at atmospheric pressure.

**Air polytropic index – Polytropic process exponent**

1.0 (default) | positive scalar between [0, 1]

Exponent of the equation that governs the polytropic process relating fluid pressure and volume.

**Air density at atmospheric condition – Air density**1.225 kg/m<sup>3</sup> (default) | positive scalar

Air density at the pressure defined in the **Atmospheric pressure** parameter.

**Air dissolution model – Air entrainment model**

On (default) | Off

Whether to account for of air dissolution into the fluid network. Air dissolution into the liquid is modeled between the **Atmospheric pressure** and the **Pressure at which all entrained air is dissolved** by Henry's Law.

**Pressure at which all entrained air is dissolved – Upper pressure limit for air entrainment**

3 MPa (default) | positive scalar

Upper pressure limit for air entrainment into the fluid.

**Dependencies**

To enable this parameter, set **Air dissolution model** to On.

## Version History

Introduced in R2020a

## References

[1] Massachusetts Institute of Technology (MIT), *Thermophysical properties of seawater database*. <http://web.mit.edu/seawater>.

- [2] K.G. Nayar, M.H. Sharqawy, L.D. Banchik, J.H. Lienhard V. "Thermophysical properties of seawater: A review and new correlations that include pressure dependence." *Desalination* 390 (July 2016): 1-24.
- [3] M.H. Sharqawy, J.H. Lienhard V, S.M. Zubair. "Thermophysical properties of seawater: A review of existing correlations and data." *Desalination and Water Treatment* 16, no. 1-3 (April 2010): 354-380.
- [4] I.H. Bell, J. Wronski, S. Quoilin, V. Lemort. "Pure and Pseudo-pure Fluid Thermophysical Property Evaluation and the Open-Source Thermophysical Property Library CoolProp." *Industrial & Engineering Chemistry Research* 53, no. 6 (February 12, 2014): 2498-2508.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Isothermal Liquid Properties (IL) | "Isothermal Liquid Modeling Options"

### **Topics**

"Fluid Models with Entrained Air"

## Hydraulic Fluid

Working fluid properties, set by selecting from list of predefined fluids

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Hydraulic Utilities



### Description

The Hydraulic Fluid block lets you specify the type of hydraulic fluid used in a loop of hydraulic blocks. It provides the hydraulic fluid properties, such as kinematic viscosity, density, and bulk modulus, for all the hydraulic blocks in the loop. These fluid properties are assumed to be constant during simulation time. The density is determined by the type of fluid, while kinematic viscosity additionally requires that the temperature is specified.

The bulk modulus value shown in the block dialog box is the bulk modulus of pure liquid, and is determined by the type of fluid and by the temperature. When the fluid properties are used in hydraulic blocks, such as Constant Volume Hydraulic Chamber or Variable Hydraulic Chamber, the fluid is represented as a mixture of liquid and a small amount of entrained, nondissolved gas, which is specified in the Hydraulic Fluid block as **Relative amount of trapped air**. The mixture bulk modulus in these blocks is determined as:

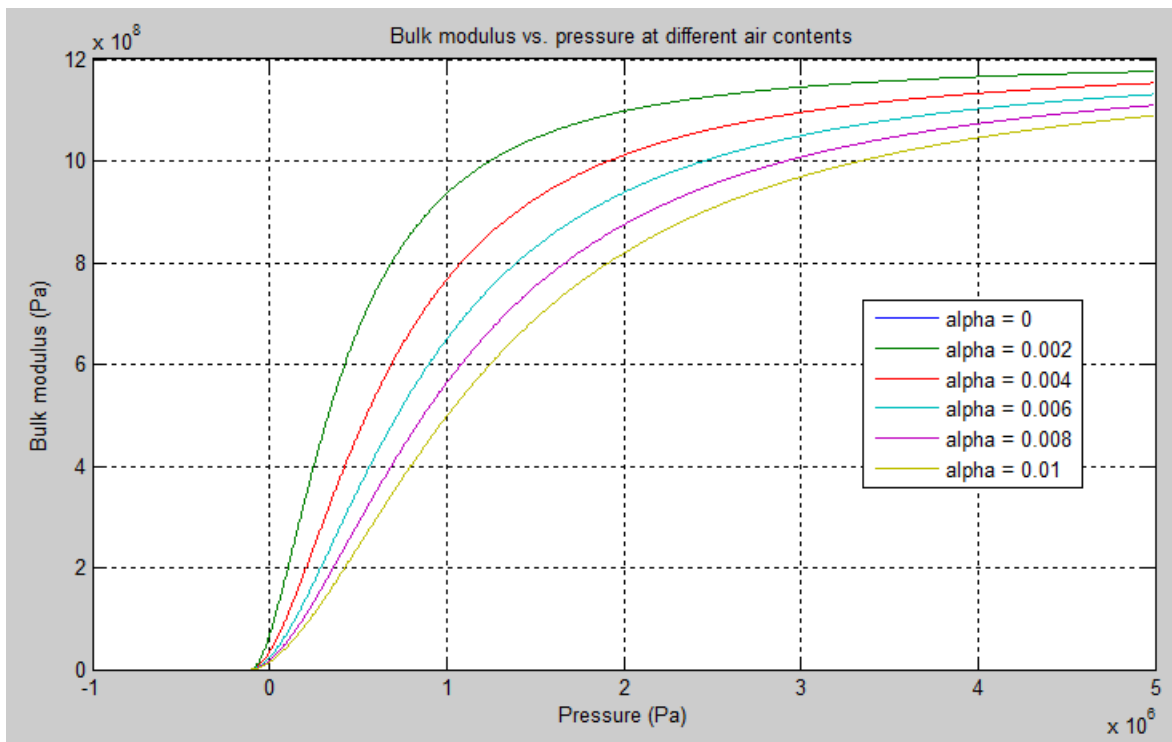
$$E = E_l \frac{1 + \alpha \left( \frac{p_a}{p_a + p} \right)^{1/n}}{1 + \alpha \frac{p_a^{1/n}}{n \cdot (p_a + p)^{\frac{n+1}{n}}} E_l}$$

where

$E_l$	Pure liquid bulk modulus
$p_a$	Atmospheric pressure
$\alpha$	Relative gas content at atmospheric pressure, $\alpha = V_G/V_L$
$V_G$	Gas volume at atmospheric pressure
$V_L$	Volume of liquid
$n$	Gas-specific heat ratio

The main objective of representing fluid as a mixture of liquid and gas is to introduce an approximate model of cavitation, which takes place in a chamber if pressure drops below fluid vapor saturation level. As it is seen in the graph below, the bulk modulus of a mixture decreases at  $p \rightarrow p_a$ , thus considerably slowing down further pressure change. At high pressure,  $p \gg p_a$ , a small amount of nondissolved gas has practically no effect on the system behavior.





Cavitation is an inherently thermodynamic process, requiring consideration of multiple-phase fluids, heat transfers, and so on, and as such cannot be accurately simulated with Simscape Fluids software. But the simplified version implemented in the block is good enough to signal if pressure falls below dangerous level, and to prevent computation failure that normally occurs at negative pressures.

The Hydraulic Fluid block offers a selection of predefined fluids. See “Fluid Properties” on page 1-1123 for how you can get information on the fluid properties used in the block. Once you select a fluid name, you can also specify the temperature of the fluid and the relative amount of entrained, nondissolved gas.

Each topologically distinct hydraulic loop in a diagram requires the properties of its working fluid to be specified. You can specify these properties either by selecting a predefined fluid using a Hydraulic Fluid block, or by specifying parameters of a custom fluid using a Custom Hydraulic Fluid block, which is available in the Simscape Foundation library. If no Hydraulic Fluid block or Custom Hydraulic Fluid block is attached to a loop, the hydraulic blocks in this loop use the default fluid, which is equivalent to fluid defined by a Custom Hydraulic Fluid block with the default parameter values.

### Fluid Properties

When you select a fluid type, the **Fluid Properties** section in the block dialog box displays these fluid property values:

- Density  $\text{kg/m}^3$
- Viscosity (cSt)
- Bulk modulus (Pa)

You can also get information on the fluids and their properties through the MATLAB command line. In the following example, the first command brings you the list of available fluids, and the second command plots the properties of a selected fluid from the list, in this case, Skydrol LD-4.

- 1 In the MATLAB Command Window, type:

```
props = sh_stockfluidproperties
```

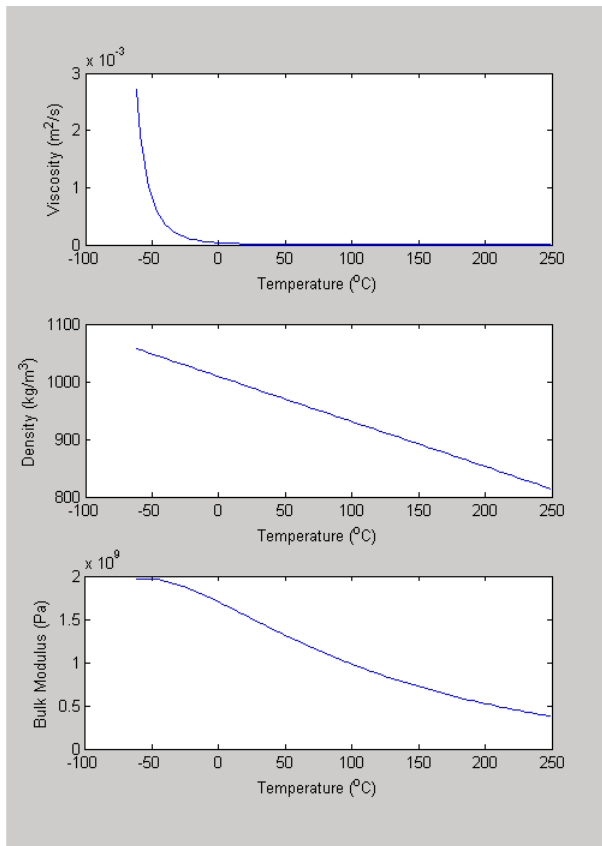
The system responds with a list of available fluids:

```
props =  
  
    skydrol_ld_4: [1x1 struct]  
    skydrol_500_4: [1x1 struct]  
    skydrol_5: [1x1 struct]  
    hy_jet: [1x1 struct]  
    f_83282: [1x1 struct]  
    f_5606: [1x1 struct]  
    f_87257: [1x1 struct]  
    oil_10w: [1x1 struct]  
    oil_30w: [1x1 struct]  
    oil_50w: [1x1 struct]  
    oil_sae_30: [1x1 struct]  
    oil_sae_50: [1x1 struct]  
    atf_dexron: [1x1 struct]  
    iso_vg_32: [1x1 struct]  
    gasoline: [1x1 struct]  
    diesel_fuel: [1x1 struct]  
    jet_fuel: [1x1 struct]  
    water_glycol: [1x1 struct]
```

- 2 To plot the properties of the first fluid in the list, Skydrol LD-4, type:

```
props.skydrol_ld_4.plot()
```

The plot window opens:



Fluid properties for the Skydrol family of hydraulic fluids were obtained from literature provided by the manufacturer, Solutia, Inc. More information is available on their website at: <http://www.skydrol.com>.

## Ports

### Conserving

#### G – Connection port

hydraulic

Hydraulic conserving port that connects the block to the network. You can connect it to any point on a hydraulic connection line in a block diagram. When you connect the Hydraulic Fluid block to a connection line, the software automatically identifies the hydraulic blocks connected to the particular circuit and propagates the fluid properties to all the blocks in the circuit.

## Parameters

### Hydraulic fluid index – Hydraulic fluid type

Skydrol LD-4 (default) | Skydrol 500B-4 | Skydrol 5 | HyJet-4A | Fluid MIL-F-83282 | Fluid MIL-F-5606 | Fluid MIL-F-87257 | Oil-10W | Oil-30W | Oil-50W | Oil SAE-30 | Oil SAE-50 | Transmission fluid ATF (Dexron III) | ISO VG 22 (ESSO UNIVIS N 22) | ISO VG 32 (ESSO UNIVIS N 32) | ISO VG 46 (ESSO UNIVIS N 46) | Brake fluid DOT3 | Brake fluid DOT4 | Brake fluid DOT5 | Gasoline | Diesel fuel | Jet fuel | Water-Glycol 60/40 | Water

Hydraulic fluid type. Select one of the predefined fluids:

- Skydrol LD-4
- Skydrol 500B-4
- Skydrol 5
- HyJet-4A
- Fluid MIL-F-83282
- Fluid MIL-F-5606
- Fluid MIL-F-87257
- Oil-10W
- Oil-30W
- Oil-50W
- Oil SAE-30
- Oil SAE-50
- Transmission fluid ATF (Dexron III)
- ISO VG 22 (ESSO UNIVIS N 22)
- ISO VG 32 (ESSO UNIVIS N 32)
- ISO VG 46 (ESSO UNIVIS N 46)
- Brake fluid DOT3
- Brake fluid DOT4
- Brake fluid DOT5
- Gasoline
- Diesel fuel
- Jet fuel
- Water-Glycol 60/40
- Water

**System temperature (degC) – Fluid temperature, in degrees C**

60 (default) | positive scalar

Fluid temperature, in degrees C.

**Relative amount of trapped air – Amount of entrained, nondissolved gas in the fluid**

0.005 (default) | scalar in the range of [0,1)

Amount of entrained, nondissolved gas in the fluid. The amount is specified as the ratio of gas volume at normal conditions to the fluid volume in the chamber. Therefore, the parameter value must be less than 1. In practice, the relative amount of trapped air is always greater than 0. If set to 0, ideal fluid is assumed.

**Viscosity derating factor – Proportionality coefficient for fluid viscosity**

1 (default) | scalar in the range of [0.5,1.5]

Proportionality coefficient that you can use to adjust fluid viscosity, if needed. Specify a value between 0.5 and 1.5.

**Pressure below absolute zero — Determines how the block handles the out-of-range assertion during simulation**

Error (default) | Warning

Determines how the block handles the out-of-range assertion during simulation:

- **Error** — If the pressure falls below absolute zero, the simulation stops and you get an error message.
- **Warning** — If the pressure falls below absolute zero, you get a warning but the simulation continues. Use this option when modeling systems where cavitation can occur in extreme cases.

**Version History****Introduced in R2006a****Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Custom Hydraulic Fluid

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Fan (MA)

Fan in moist air network

**Library:** Simscape / Fluids / Moist Air / Turbomachinery



### Description

The Fan (MA) block represents a fan in a moist air network. You can model the torque and pressure gain over the fan as a function of static pressure and flow rate or by using 1D or 2D tabulated reference pressure, shaft speed, and flow rate data.

By default, flow and pressure gain are from port **A** to port **B**. Port **C** represents the fan casing, and port **R** represents the fan shaft. You can specify the normal operating shaft direction in the **Mechanical orientation** parameter. If the shaft begins to spin in the opposite direction, the pressure difference across the fan drops to zero.

### Parameterization by Nominal Pressure, Flow Rate, and Shaft Speed

When you set the **Fan parameterization** parameter to Static pressure and flow rate at reference shaft speed, the block uses the analytical fan affinity laws and reference pressure differential to calculate the pressure gain from port **A** to port **B**:

$$p_B - p_A = \Delta p_{ref} \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2,$$

where:

- $\Delta p_{ref}$  is the reference pressure differential. The block uses a quadratic fit of the fan pressure differential values at the **Maximum static pressure gain at zero flow**, **Nominal static pressure gain**, and **Maximum volumetric flow rate at zero pressure** parameters.
- $\omega$  is the shaft angular velocity,  $\omega_R - \omega_C$ .
- $\omega_{ref}$  is the **Reference shaft speed** parameter.
- $\frac{D}{D_{ref}}$  is the **Fan diameter scale factor** parameter.

The block calculates the shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \Phi_{ref} \frac{\omega^2}{\omega_{ref}^3} \left( \frac{D}{D_{ref}} \right)^5.$$

Where  $\Phi_{ref}$  is the proportion of the pressure gain to the fan efficiency:

$$\Phi_{ref} = \frac{q_{ref} \Delta p_{ref}}{\eta_{ref}}.$$

When you set the **Shaft power specification** parameter to Fan efficiency, the block uses a quadratic fit of efficiency between the fan peak performance,  $\eta_{nom}$ , and 0.  $\eta_{nom}$  is equivalent to the

**Nominal efficiency** parameter, which the block interprets as the peak efficiency. If you set the **Shaft power specification** parameter to Brake power, the block derives the nominal fan efficiency from the nominal brake power,  $\Phi_{nom}$ , at peak or nominal conditions:

$$\eta_{nom} = \frac{q_{nom} \Delta p_{nom}}{\Phi_{nom}}.$$

The block assumes the efficiency is zero when there is no flow or when the flow reaches the maximum volumetric flow rate at zero pressure. The block uses the current flow  $q$  to compute the reference flow rate as:

$$q_{ref} = q \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

### 1-D Tabulated Data Parameterization: Pressure as a Function of Flow Rate at Reference Shaft Speed

When you set the **Fan parameterization** parameter to 1D tabulated data - static pressure vs. flow rate at reference shaft speed, you can model fan performance as a function of volumetric flow rate. The block interpolates the pressure gain from port **A** to port **B** from the 1-D **Static pressure gain vector** parameter,  $\Delta p_{ref}(q_{ref})$ :

$$p_B - p_A = \Delta p_{ref}(q_{ref}) \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{\omega}{\omega_{ref}} \right)^2 \left( \frac{D}{D_{ref}} \right)^2.$$

Here,  $\rho$  is the moist air density, and  $\rho_{ref}$  is the reference density, which is equivalent to the **Reference density** parameter. The block calculates the shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \Phi_{ref}(q_{ref}) \frac{\omega^2}{\omega_{ref}^3} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where  $\rho_{ref}$  is the **Reference density**.

The block uses the current flow  $q$  to compute the reference flow rate:

$$q_{ref} = q \frac{\omega_{ref}}{\omega} \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### 2-D Tabulated Data Parameterization: Pressure as a Function of Shaft Speed and Flow Rate

When you set the **Fan parameterization** parameter to 2D tabulated data - static pressure vs. shaft speed and flow rate, you can model fan performance as a 2-D function of volumetric flow rate and angular velocity. The block interpolates the pressure gain from port **A** to port **B** from the 2-D **Static pressure gain table**,  $\mathbf{dp}(\mathbf{w}, \mathbf{q})$  parameter. The block defines the reference pressure gain,  $\Delta p_{ref}(q_{ref}, \omega)$ , as

$$p_B - p_A = \Delta p_{ref}(q_{ref}, \omega) \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^2.$$

The block calculates shaft torque from the reference mechanical power and the fan affinity laws:

$$\tau = \frac{\Phi_{ref}(q_{ref}, \omega)}{\omega} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where the reference mechanical power is a function of the reference flow rate and the current shaft speed.

The block uses the current flow  $q$  to compute the reference flow rate:

$$q_{ref} = q \left( \frac{D_{ref}}{D} \right)^3.$$

When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### Missing Data

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table, dp(w,q)**, **Efficiency table, eta(w,q)**, and **Mechanical power table, W(w,q)** parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### 2-D Tabulated Data Parameterization: Flow Rate as a Function of Shaft Speed and Pressure

When you set the **Fan parameterization** parameter to 2D tabulated data - flow rate vs. shaft speed and static pressure, you can model the flow rate through the fan as a 2-D function of pressure and angular velocity. The volumetric flow rate is interpolated from the 2-D **Volumetric flow rate table, q(w,dp)** parameter,  $q_{ref}$ . The reference flow rate is a function of the reference pressure gain,  $\Delta p_{ref}$ , and the current shaft speed,  $\omega$ :

$$q = q_{ref}(\Delta p_{ref}, \omega) \left( \frac{D}{D_{ref}} \right)^3,$$

where the reference pressure gain derives from the pressure differential over the fan:

$$\Delta p_{ref} = (p_B - p_A) \left( \frac{\rho_{ref}}{\rho} \right) \left( \frac{D_{ref}}{D} \right)^2.$$

The shaft torque derives from the reference mechanical power and the fan affinity laws:

$$\tau = \frac{\Phi_{ref}(\Delta p_{ref}, \omega)}{\omega} \left( \frac{\rho}{\rho_{ref}} \right) \left( \frac{D}{D_{ref}} \right)^5,$$

where the reference mechanical power is a function of the reference flow rate and the current shaft speed.



When the simulation is outside the range of the provided tables, the block extrapolates pressure based on the average slope of the fan curves and the reference torque to the nearest point.

### Missing Data

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w,dp)$ , Efficiency table,  $\eta(w,dp)$ , and Mechanical power table,  $W(w,dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### Power and Efficiency

You can specify shaft power as either fan efficiency or brake power.

The block calculates efficiency as

$$\eta = \frac{\Phi_{fluid}}{\Phi_{brake}},$$

where the *brake power*, or mechanical power measured at the shaft, is

$$\Phi_{brake} = \tau\omega.$$

The block calculates fluid power as

$$\Phi_{fluid} = q(p_B - p_A).$$

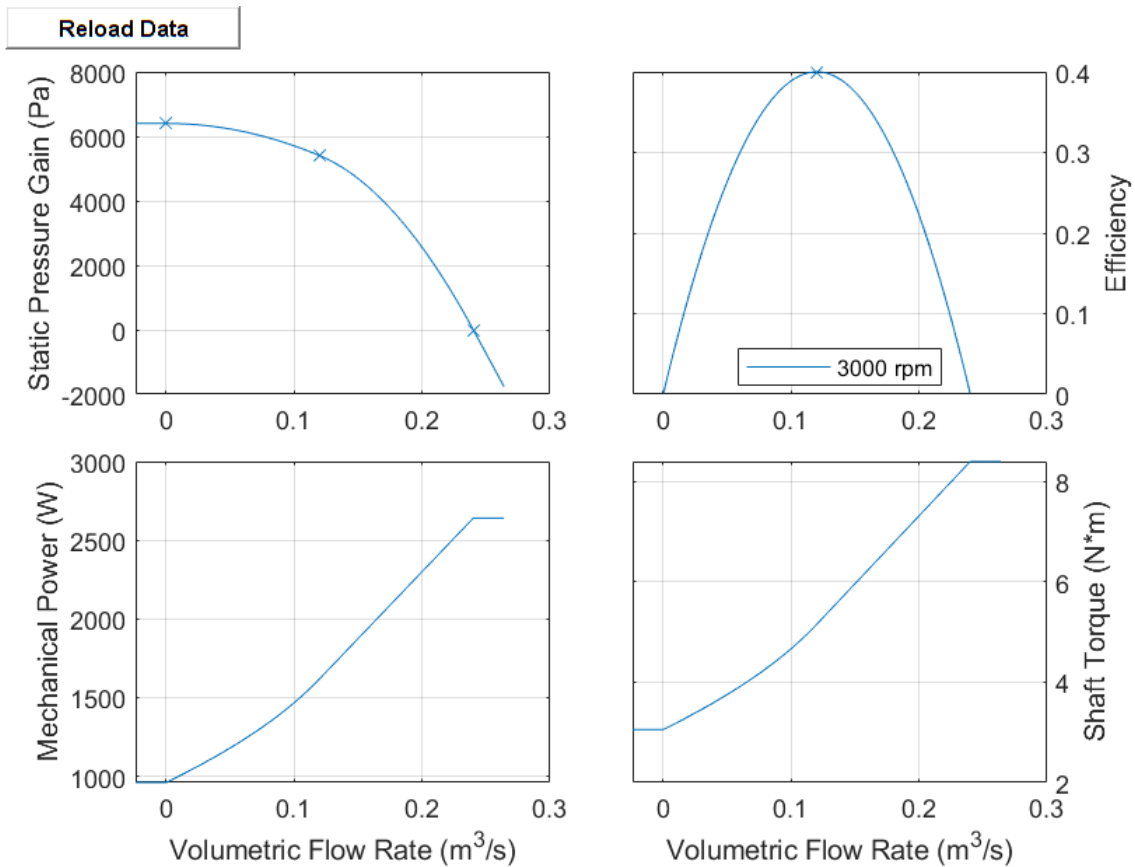
The block calculates torque as

$$\tau = \frac{\Phi_{brake}}{\omega}.$$

### Visualizing the Fan Curve

You can check the parameterized fan performance by plotting the pressure, power, efficiency, and torque as a function of the flow. To generate a plot of the current fan settings, right-click on the block and select **Fluids > Plot Fan Characteristics**. If you change settings or data, click **Apply** on the block parameters and click **Reload Data** on the fan curve figure.

The default block parameterization results in these plots:



### Assumptions and Limitations

- If the shaft rotates opposite to the specified mechanical orientation, pressure difference across the block drops to zero and the results may not be accurate.
- The block assumes that the fan is quasi-steady.
- The block simulates fan performance in terms of static pressure rise, and not total fan pressure.

### Ports

#### Conserving

##### A – Fluid entry

moist air

Moist air conserving port associated with the fluid.

##### B – Fluid exit

moist air

Moist air conserving port associated with the fluid.

##### R – Shaft

mechanical rotational

Mechanical rotational conserving port associated with the shaft.

### **C – Casing**

mechanical rotational

Mechanical rotational conserving port associated with the casing.

## **Parameters**

### **Fan parameterization – Fan performance model**

Static pressure and flow rate at reference shaft speed (default) | 1D tabulated data - static pressure vs. flow rate at reference shaft speed | 2D tabulated data - static pressure vs. shaft speed and flow rate | 2D tabulated data - flow rate vs. shaft speed and static pressure

Fan performance model, specified as:

- **Static pressure and flow rate at reference shaft speed:** Specify fan performance based on typical, nominal, or rated pressure gain and volumetric flow rate.
- **1D tabulated data – static pressure vs flow rate at reference shaft speed:** Specify fan performance based on interpolation of pressure gain data as a function of volumetric flow rate.
- **2D tabulated data – static pressure vs shaft speed and flow rate:** Specify fan performance based on the interpolation of pressure gain data as a function of shaft speed and volumetric flow rate.
- **2D tabulated data – flow rate vs shaft speed and static pressure:** Specify fan performance based on the interpolation of volumetric flow rate data as a function of shaft speed and pressure gain.

### **Shaft power specification – Power definition**

Fan efficiency (default) | Brake power

Fan power specification, specified as:

- **Fan efficiency:** Derive the mechanical power from the fan efficiency.
- **Mechanical power:** Specify the mechanical power directly.

### **Nominal volumetric flow rate – Flow rate at reference shaft speed**

0.12 m<sup>3</sup>/s (default) | positive scalar

Volumetric flow rate through the fan at the reference shaft speed under nominal, typical, or rated operating conditions.

### **Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

### **Nominal static pressure gain – Pressure gain at reference shaft speed**

5400 Pa (default) | positive scalar

Pressure increase from port **A** to port **B** at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Nominal efficiency — Efficiency at reference shaft speed**

0.40 (default) | positive scalar

Efficiency of converting the shaft power to fluid power at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set:

- **Fan parameterization** to Static pressure and flow rate at reference shaft speed.
- **Shaft power specification** to Fan efficiency.

**Nominal mechanical power — Power at nominal efficiency**

1620 W (default) | positive scalar

Mechanical power driving moist air flow at the reference shaft speed under nominal, typical, or rated operating conditions.

**Dependencies**

To enable this parameter, set:

- **Fan parameterization** to Static pressure and flow rate at reference shaft speed.
- **Shaft power specification** to Brake power.

**Maximum static pressure gain at zero flow — Maximum pressure at reference shaft speed**

6400 Pa (default) | positive scalar

Pressure increase from port **A** to port **B** at the reference shaft speed when there is no flow through the fan.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Maximum volumetric flow rate at zero pressure — Maximum flow rate at reference shaft speed**

0.24 m<sup>3</sup>/s (default) | positive scalar

Free-delivery volumetric flow rate at the reference shaft speed and constant pressure.

**Dependencies**

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed.

**Reference shaft speed — Fan curve reference speed**

3000 rpm (default) | positive scalar

Reference shaft angular velocity corresponding to the fan characteristic curve data.

#### Dependencies

To enable this parameter, set **Fan parameterization** to Static pressure and flow rate at reference shaft speed or 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Volumetric flow rate vector — Fan curve flow rate vector

[.0278, .0556, .0833, .111, .139, .167] m<sup>3</sup>/s (default) | vector

Vector of volumetric flow rate grid points for the 1-D interpolation of the fan characteristic curve. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Static pressure gain vector — Pressure gain for given volumetric flow rate

[6410, 6375, 6018, 5366, 4501, 3609] Pa (default) | vector

Vector of pressure gain data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The pressure gain is the increase in pressure from port **A** to port **B** at the reference shaft speed. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed.

#### Efficiency vector — Efficiency for given volumetric flow rate

[.257, .394, .453, .47, .459, .415] (default) | vector

Vector of fan efficiency data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The efficiency is the ratio of fluid power to shaft mechanical power at the reference shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed and **Shaft power specification** to Fan efficiency.

#### Mechanical power vector — Power for parameterization of torque

[693, 900, 1107, 1267, 1363, 1452] W (default) | 1-by-n vector

Vector of shaft mechanical power data points. Each element in the vector corresponds to an element in the **Volumetric flow rate vector** parameter. The mechanical power is the power that drives the fan at the reference shaft speed. These values can be negative if the fan data extends beyond the normal operating region.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed and **Shaft power specification** to Brake power.

**Reference density – Density associated with fan curve data**

1.2 kg/m<sup>3</sup> (default) | positive scalar

Moist air density for a given characteristic fan curve.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 1D tabulated data - static pressure vs. flow rate at reference shaft speed, 2D tabulated data - static pressure vs. shaft speed and flow rate or 2D tabulated data - flow rate vs. shaft speed and static pressure.

**Shaft speed vector,  $w$  – Shaft angular velocity for given**

[2400; 3000; 3600] rpm (default) | vector

Vector of shaft angular velocity grid points for the 2-D interpolation of the fan characteristic curves.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate or 2D tabulated data - flow rate vs. shaft speed and static pressure.

**Volumetric flow rate vector,  $q$  – Flow rate for parameterization of pressure gain**

[.0278, .0556, .0833, .111, .139, .167] m<sup>3</sup>/s (default) | 1-by- $n$  vector

Vector of volumetric flow rate grid points for the 2-D interpolation of the fan characteristic curves. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate.

**Static pressure gain table,  $dp(w,q)$  – Pressure for parameterization of pressure**

[4111, 4010, 3551, 2881, 2167, 1453; 6410, 6375, 6018, 5366, 4501, 3609; 9217, 9285, 9022, 8428, 7552, 6482] Pa (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of pressure gain data points for the 2-D interpolation of the pressure gain. The pressure gain is the increase in pressure from port **A** to port **B**. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- $N$  is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial

numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate.

#### Efficiency table, $eta(w,q)$ — Efficiency for parameterization of torque

[.3, .434, .468, .459, .4, .3; .257, .394, .453, .47, .459, .415; .225, .359, .434, .461, .47, .459] 1 (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of efficiency data points for the 2-D interpolation of torque. The efficiency is the ratio of fluid power to shaft mechanical power. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter.
- *N* is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate and **Shaft power specification** to Fan efficiency.

#### Mechanical power table, $W(w,q)$ — Mechanical power for parameterization of torque

[381, 514, 632, 697, 753, 809; 693, 900, 1107, 1267, 1363, 1452; 1139, 1438, 1732, 2029, 2233, 2358] *W* (default) | *M*-by-*N* matrix

*M*-by-*N* table of mechanical power data points for the 2-D interpolation of torque. These values can be negative if the fan data extends beyond the normal operating region. The mechanical power is the power that drives the fan. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- *N* is the number of elements in the **Volumetric flow rate vector,  $q$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Static pressure gain table,  $dp(w,q)$** , **Efficiency table,  $\eta(w,q)$** , and **Mechanical power table,  $W(w,q)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - static pressure vs. shaft speed and flow rate and **Shaft power specification** to Brake power.

#### Static pressure gain vector, $dp$ — Pressure for parameterization of flow rate

[31, 62, 93, 124] Pa (default) | 1-by- $N$  vector

Vector of pressure gain grid points for the 2-D interpolation of the fan characteristic curves. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.

#### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure.

#### Volumetric flow rate table, $q(w,dp)$ — Flow rate for parameterization of flow rate

[.802, .759, .703, .611; .936, .902, .862, .81; 1.056, 1.027, .994, .956]  $m^3/s$  (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rate data points for the 2-D interpolation of volumetric flow rate. When **Shaft power specification** is Brake power, the fan data can extend beyond the normal operating region, and these values can be negative.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- $N$  is the number of elements in the **Static pressure gain vector,  $Dp$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w,dp)$** , **Efficiency table,  $\eta(w,dp)$** , and **Mechanical power table,  $W(w,dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.



### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure.

### Efficiency table, $\eta(w, dp)$ — Efficiency for parameterization of torque

[.088, .162, .22, .261; .068, .128, .18, .222; .055, .105, .148, .188] (default)  
| *M*-by-*N* matrix

*M*-by-*N* matrix of efficiency data points for the 2-D interpolation of torque. The efficiency is the ratio of fluid power to shaft mechanical power. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter.
- *N* is the number of elements in the **Static pressure gain vector,  $Dp$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w, dp)$** , **Efficiency table,  $\eta(w, dp)$** , and **Mechanical power table,  $W(w, dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

### Dependencies

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure and **Shaft power specification** to Fan efficiency.

### Mechanical power table, $W(w, dp)$ — Mechanical power for parameterization of torque

[283, 290, 297, 290; 427, 437, 445, 452; 595, 606, 625, 631] W (default) | *M*-by-*N* matrix

*M*-by-*N* matrix of mechanical power data points for the 2-D interpolation of torque. These values can be negative if the fan data extends beyond the normal operating region. The mechanical power is the power that drives the fan. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Shaft speed vector,  $w$**  parameter. The elements corresponding to zero flow rate must be in strictly ascending order.
- *N* is the number of elements in the **Static pressure gain vector,  $Dp$**  parameter.

If your table has unknown data points, use NaN in place of these values. The block fills in the NaN elements by extrapolating based on the average slope of the fan curves. Do not use artificial numerical values because these values distort fan behavior when operating in that region. When using unknown data:

- The NaN elements in the table must be contiguous.
- The positions of the NaN elements in the **Volumetric flow rate table,  $q(w, dp)$** , **Efficiency table,  $\eta(w, dp)$** , and **Mechanical power table,  $W(w, dp)$**  parameters must match each other.
- NaN elements must be located in the upper-right portion of the table, which corresponds to the highest volumetric flow rate and lowest shaft speed.

**Dependencies**

To enable this parameter, set **Fan parameterization** to 2D tabulated data - flow rate vs. shaft speed and static pressure and **Shaft power specification** to Brake power.

**Fan diameter scale factor — Model-to-reference scale factor**

1 (default) | positive scalar

Geometric scale factor to increase or decrease the size of the simulated fan from the given fan parameterization. The scaling may not be accurate for scale factors much larger or much smaller than 1.

**Mechanical orientation — Rotational orientation**

Positive angular velocity of port R relative to port C corresponds to normal fan operation (default) | Negative angular velocity of port R relative to port C corresponds to normal fan operation

Normal operating shaft direction. By default, flow and pressure gain are from port **A** to port **B**.

**Inlet flow area (port A) — Port A area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the moist air flow at the fan inlet.

**Outlet flow area (port B) — Port B area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the moist air flow at the fan outlet.

## Version History

**Introduced in R2021b****Extend performance beyond normal operating conditions**

Both the 1-D and 2-D parameterizations now allow negative values. When simulation is outside the range of the provided table, block extrapolates the pressure based on the average slope of the fan curves.

You can now use NaN elements where data is unavailable. These 2-D tabulated fan parameters support contiguous NaN elements in the upper-right portion of the table:

- **Static pressure gain table, dp(w,q)**
- **Efficiency table, eta(w,q)**
- **Mechanical power table, W(w,q)**
- **Volumetric flow rate table, q(w,dp)**
- **Efficiency table, eta(w,dp)**
- **Mechanical power table, W(w,dp)**

For each block, if the shaft rotates opposite to the specified mechanical orientation, the pressure difference across the block drops to zero and the results may not be accurate.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Fan (G)

# Hydraulic Pipeline

Hydraulic pipeline with resistive and fluid compressibility properties



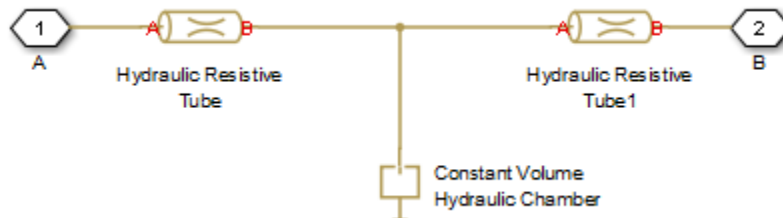
## Library

Pipelines

## Description

The Hydraulic Pipeline block models hydraulic pipelines with circular and noncircular cross sections. The block accounts for friction loss along the pipe length and for fluid compressibility. The block does not account for fluid inertia and cannot be used for predicting effects like water hammer or changes in pressure caused by fluid acceleration.

The model is built of Simscape Foundation library building blocks and its schematic diagram is shown below.



The Hydraulic Resistive Tube blocks account for friction losses, while the Constant Volume Hydraulic Chamber block accounts for fluid compressibility. By using the block parameters, you can set the model to simulate pipeline with rigid or flexible walls, including simulation of hydraulic hoses with elastic and viscoelastic properties.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

## Basic Assumptions and Limitations

- Flow is assumed to be fully developed along the pipe length.
- Fluid inertia is not taken into account.

## Parameters

### Pipe cross section type

The type of pipe cross section: `Circular` or `Noncircular`. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is `Circular`.

### Pipe internal diameter

Pipe internal diameter. The parameter is used if **Pipe cross section type** is set to `Circular`. The default value is `0.01` m.

### Noncircular pipe cross-sectional area

Pipe cross-sectional area. The parameter is used if **Pipe cross section type** is set to `Noncircular`. The default value is `1e-4` m<sup>2</sup>.

### Noncircular pipe hydraulic diameter

Hydraulic diameter of the pipe cross section. The parameter is used if **Pipe cross section type** is set to `Noncircular`. The default value is `0.0112` m.

### Geometrical shape factor

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on. The default value is 64, which corresponds to a pipe with a circular cross section.

### Pipe length

Pipe geometrical length. The default value is 5 m.

### Aggregate equivalent length of local resistances

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. This length is added to the geometrical pipe length only for hydraulic resistance computation. The fluid volume depends on pipe geometrical length only. The default value is 1 m.

### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is `15e-6` m, which corresponds to drawn tubing.

### Laminar flow upper margin

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

### Turbulent flow lower margin

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

### Pipe wall type

The parameter is available only for circular pipes and can have one of two values: `Rigid Wall` or `Flexible Wall`. If the parameter is set to `Rigid Wall`, wall compliance is not taken into account, which can improve computational efficiency. The value `Flexible Wall` is recommended for hoses and metal pipes where wall compliance can affect the system behavior. The default value is `Rigid Wall`.

**Static pressure-diameter coefficient**

Coefficient that establishes relationship between the pressure and the internal diameter at steady-state conditions. This coefficient can be determined analytically for cylindrical metal pipes or experimentally for hoses. The parameter is used if the **Pipe wall type** parameter is set to **Flexible Wall**. The default value is  $2e-12$  m/Pa.

**Viscoelastic process time constant**

Time constant in the transfer function that relates pipe internal diameter to pressure variations. By using this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The value is determined experimentally or provided by the manufacturer. The parameter is used if the **Pipe wall type** parameter is set to **Flexible Wall**. The default value is  $0.01$  s.

**Specific heat ratio**

Gas-specific heat ratio for the Constant Volume Hydraulic Chamber block. The default value is  $1.4$ .

**Initial pressure**

Initial pressure in the pipe. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Initial Conditions Computation". The default value is  $0$ .

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Pipe cross section type**
- **Pipe wall type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the values of the **Pipe cross section type** and **Pipe wall type** parameters at the time the model entered Restricted mode.

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Linear Hydraulic Resistance | Hydraulic Resistive Tube | Segmented Pipeline

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Hydraulic Pipe LP

Hydraulic pipeline with resistive, fluid compressibility, and elevation properties



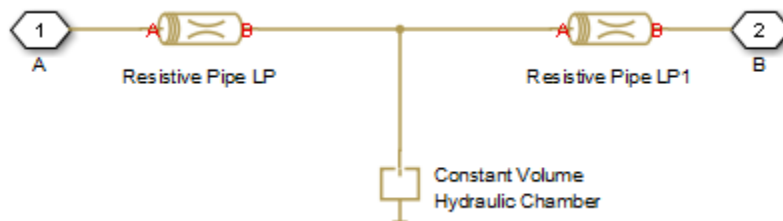
### Library

Low-Pressure Blocks

### Description

The Hydraulic Pipe LP block models hydraulic pipelines with circular and noncircular cross sections. The block accounts for friction loss along the pipe length and for fluid compressibility. The block does not account for fluid inertia and cannot be used for predicting effects like water hammer or changes in pressure caused by fluid acceleration.

The model is a structural model and its schematic diagram is shown below.



The Resistive Pipe LP blocks account for friction losses, while the Constant Volume Hydraulic Chamber block accounts for fluid compressibility. To reduce model complexity, you can use this block to simulate not only a pipe itself, but also a combination of pipes and local resistances such as bends, fittings, inlet and outlet losses, associated with the pipe. You must convert the resistances into their equivalent lengths, and then sum up all the resistances to obtain their aggregate length. Then add this length to the pipe geometrical length. By using the block parameters, you can set the model to simulate pipeline with rigid or flexible walls, including simulation of hydraulic hoses with elastic and viscoelastic properties.

The difference in elevation between ports A and B is distributed evenly between pipe segments.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

### Basic Assumptions and Limitations

- Flow is assumed to be fully developed along the pipe length.



- Fluid inertia is not taken into account.

## Parameters

- “Basic Parameters Tab” on page 1-1147
- “Wall Compliance Tab” on page 1-1148
- “Vertical Position Tab” on page 1-1148

### Basic Parameters Tab

#### Pipe cross section type

The type of pipe cross section: **Circular** or **Noncircular**. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is **Circular**.

#### Pipe internal diameter

Pipe internal diameter. The parameter is used if **Pipe cross section type** is set to **Circular**. The default value is 0.01 m.

#### Noncircular pipe cross-sectional area

Pipe cross-sectional area. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is  $1e-4 \text{ m}^2$ .

#### Noncircular pipe hydraulic diameter

Hydraulic diameter of the pipe cross section. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is 0.0112 m.

#### Geometrical shape factor

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on. The default value is 64, which corresponds to a pipe with a circular cross section.

#### Pipe length

Pipe geometrical length. The default value is 5 m.

#### Aggregate equivalent length of local resistances

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. This length is added to the geometrical pipe length only for hydraulic resistance computation. The fluid volume depends on pipe geometrical length only. The default value is 1 m.

#### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer’s catalogs. The default value is  $15e-6 \text{ m}$ , which corresponds to drawn tubing.

#### Laminar flow upper Reynolds number

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

**Turbulent flow lower Reynolds number**

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

**Initial pressure**

Gauge pressure in the pipe at time zero. The default value is 0 Pa.

**Wall Compliance Tab****Pipe wall type**

The parameter is available only for circular pipes and can have one of two values: **Rigid** or **Flexible**. If the parameter is set to **Rigid**, wall compliance is not taken into account, which can improve computational efficiency. The value **Flexible** is recommended for hoses and metal pipes where wall compliance can affect the system behavior. The default value is **Rigid**.

**Static pressure-diameter coefficient**

Coefficient that establishes relationship between the pressure and the internal diameter at steady-state conditions. This coefficient can be determined analytically for cylindrical metal pipes or experimentally for hoses. The parameter is used if the **Pipe wall type** parameter is set to **Flexible**. The default value is  $2e-12$  m/Pa.

**Viscoelastic process time constant**

Time constant in the transfer function that relates pipe internal diameter to pressure variations. By using this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The value is determined experimentally or provided by the manufacturer. The parameter is used if the **Pipe wall type** parameter is set to **Flexible**. The default value is 0.01 s.

**Specific heat ratio**

Gas-specific heat ratio for the Constant Volume Hydraulic Chamber block. The default value is 1.4. If **Pipe cross section type** is set to **Noncircular**, then this is the only parameter on the Wall Compliance tab.

**Vertical Position Tab****Port A elevation from reference plane**

Vertical position of port **A** with respect to a reference plane. The reference plane is assumed to be the same as that used in the **Port B elevation from reference plane** parameter. The default value is 0m.

**Port B elevation from reference plane**

Vertical position of port **B** with respect to a reference plane. The reference plane is assumed to be the same as that used in the **Port A elevation from reference plane** parameter. The default value is 0m.

**Gravitational acceleration**

Value of the gravitational acceleration constant ( $g$ ). The block uses this value to compute the pressure differential between the ports due to a change in elevation. The default value is  $9.80665$  m/s<sup>2</sup>.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Pipe cross section type**
- **Pipe wall type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the values of the **Pipe cross section type** and **Pipe wall type** parameters at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2009a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Hydraulic Pipeline | Hydraulic Pipe LP with Variable Elevation | Linear Hydraulic Resistance | Resistive Pipe LP | Resistive Pipe LP with Variable Elevation | Hydraulic Resistive Tube | Segmented Pipeline | Segmented Pipe LP

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Hydraulic Pipe LP with Variable Elevation

Hydraulic pipeline with resistive, fluid compressibility, and variable elevation properties



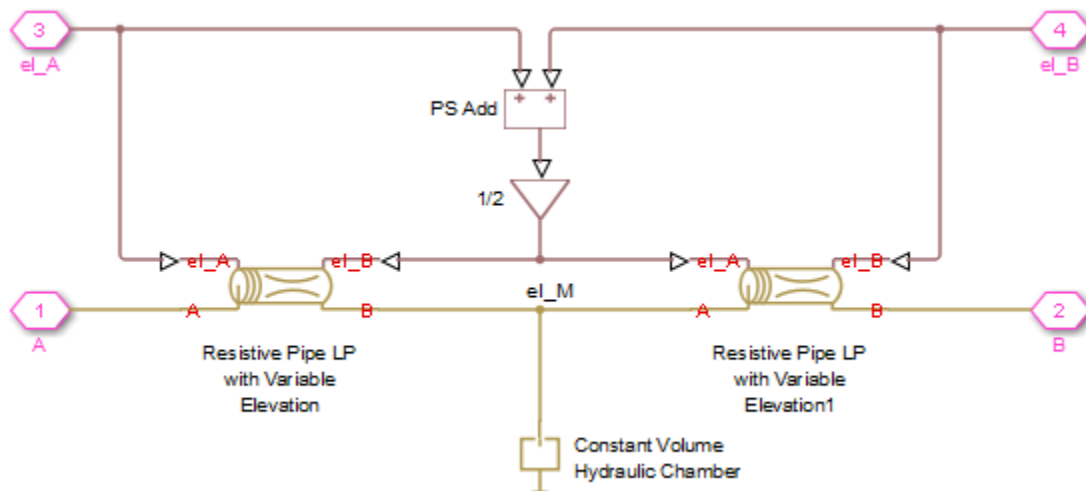
### Library

Low-Pressure Blocks

### Description

The Hydraulic Pipe LP with Variable Elevation block models hydraulic pipelines with circular and noncircular cross sections. The block accounts for friction loss along the pipe length and for fluid compressibility. The block does not account for fluid inertia and cannot be used for predicting effects like water hammer or changes in pressure caused by fluid acceleration. Use this block for low-pressure system simulation in which the pipe ends change their positions with respect to the reference plane. The elevations are provided through respective physical signal inputs.

The model is a structural model and its schematic diagram is shown below.



The Resistive Pipe LP with Variable Elevation blocks account for friction losses, while the Constant Volume Hydraulic Chamber block accounts for fluid compressibility. To reduce model complexity, you can use this block to simulate not only a pipe itself, but also a combination of pipes and local resistances such as bends, fittings, inlet and outlet losses, associated with the pipe. You must convert the resistances into their equivalent lengths, and then sum up all the resistances to obtain their aggregate length. Then add this length to the pipe geometrical length. By using the block

parameters, you can set the model to simulate pipeline with rigid or flexible walls, including simulation of hydraulic hoses with elastic and viscoelastic properties.

The difference in elevation between ports A and B is assumed to be distributed evenly between pipe segments. Thus, the elevation of the pipe middle point is computed as

$$el\_M = \frac{el\_A + el\_B}{2}$$

where

$el\_M$	Elevation of the pipe middle point
$el\_A, el\_B$	Elevations of the pipe ends A and B, respectively

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

## Basic Assumptions and Limitations

- Flow is assumed to be fully developed along the pipe length.
- Fluid inertia is not taken into account.
- The pipe elevation is distributed evenly along the pipe length.

## Parameters

- “Basic Parameters Tab” on page 1-1151
- “Wall Compliance Tab” on page 1-1152

### Basic Parameters Tab

#### Pipe cross section type

The type of pipe cross section: **Circular** or **Noncircular**. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is **Circular**.

#### Pipe internal diameter

Pipe internal diameter. The parameter is used if **Pipe cross section type** is set to **Circular**. The default value is 0.01 m.

#### Noncircular pipe cross-sectional area

Pipe cross-sectional area. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is  $1e-4 \text{ m}^2$ .

#### Noncircular pipe hydraulic diameter

Hydraulic diameter of the pipe cross section. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is 0.0112 m.

#### Geometrical shape factor

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on. The default value is 64, which corresponds to a pipe with a circular cross section.

**Pipe length**

Pipe geometrical length. The default value is 5 m.

**Aggregate equivalent length of local resistances**

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. This length is added to the geometrical pipe length only for hydraulic resistance computation. The fluid volume depends on pipe geometrical length only. The default value is 1 m.

**Internal surface roughness height**

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is  $1.5e-5$  m, which corresponds to drawn tubing.

**Laminar flow upper Reynolds number limit**

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

**Turbulent flow lower Reynolds number limit**

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

**Gravitational acceleration**

Value of the gravitational acceleration constant ( $g$ ). The block uses this parameter to calculate time changes in pressure due to time changes in elevation. The default value is  $9.80665 \text{ m/s}^2$ .

**Initial pressure**

Gauge pressure in the pipe at time zero. The default value is 0 Pa.

**Wall Compliance Tab****Pipe wall type**

The parameter is available only for circular pipes and can have one of two values: **Rigid** or **Flexible**. If the parameter is set to **Rigid**, wall compliance is not taken into account, which can improve computational efficiency. The value **Flexible** is recommended for hoses and metal pipes where wall compliance can affect the system behavior. The default value is **Rigid**.

**Static pressure-diameter coefficient**

Coefficient that establishes relationship between the pressure and the internal diameter at steady-state conditions. This coefficient can be determined analytically for cylindrical metal pipes or experimentally for hoses. The parameter is used if the **Pipe wall type** parameter is set to **Flexible**. The default value is  $2e-12 \text{ m/Pa}$ .

**Viscoelastic process time constant**

Time constant in the transfer function that relates pipe internal diameter to pressure variations. By using this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The value is determined experimentally or provided by the manufacturer. The parameter is used if the **Pipe wall type** parameter is set to **Flexible**. The default value is 0.01 s.

### Specific heat ratio

Gas-specific heat ratio for the Constant Volume Hydraulic Chamber block. The default value is 1.4. If **Pipe cross section type** is set to **Noncircular**, then this is the only parameter on the Wall Compliance tab.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

e1\_A

Physical signal input port that controls pipe elevation at port A.

e1\_B

Physical signal input port that controls pipe elevation at port B.

## Examples

For an example of using this block, see the “Aircraft Fuel Supply System with Three Tanks” example.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2010a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

Hydraulic Pipeline | Hydraulic Pipe LP | Hydraulic Resistive Tube | Linear Hydraulic Resistance | Resistive Pipe LP | Resistive Pipe LP with Variable Elevation | Segmented Pipeline | Segmented Pipe LP

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”



# Hydraulic Single-Acting Valve Actuator

Single-acting hydraulic valve actuator

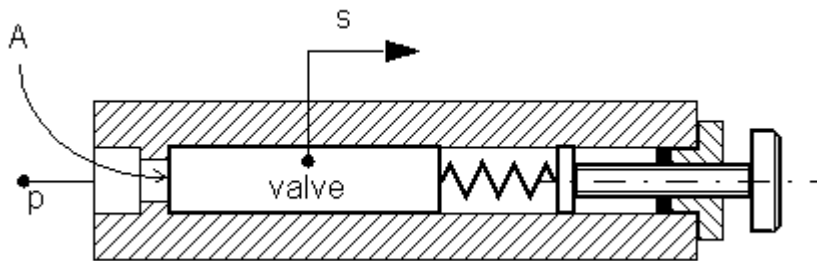


## Library

Valve Actuators

## Description

Use the Hydraulic Single-Acting Valve Actuator block as a pilot actuator for directional, pressure, or flow control valves in applications where all the forces, except spring force, and flow consumption can be neglected.



The actuator consists of a piston and a spring. The spring, which can be preloaded, tends to keep the piston at the initial position. As pressure applied to the piston develops enough force to overcome the spring preload, the piston moves to the opposite position until it reaches its maximum stroke.

The actuator is simulated according to the following equations:

$$F = p \cdot A$$

$$L = \frac{\text{stroke}}{F_{\max} - F_{pr}}$$

$$s = \begin{cases} 0 & \text{for } F < = F_{pr} \\ L \cdot (F - F_{pr}) \cdot \text{or} & \text{for } F_{pr} < F < F_{\max} \\ \text{stroke} \cdot \text{or} & \text{for } F > = F_{\max} \end{cases}$$

where

$p$	Pressure applied to the piston
-----	--------------------------------

$s$	Piston displacement
$A$	Piston area
$F$	Instantaneous spring force
$F_{pr}$	Spring preload force
$F_{max}$	Spring force at maximum piston displacement
<i>stroke</i>	Piston stroke
<i>or</i>	Actuator orientation with respect to the globally assigned positive direction. If pressure applied at port X moves the piston in positive direction, <i>or</i> equals 1. If pressure applied at port X moves the piston in negative direction, <i>or</i> equals -1.

Connection X is a hydraulic conserving port associated with the valve chamber. Connection P is a physical signal port whose output corresponds to piston displacement. Pressure applied at port X moves the piston in the positive or negative direction, depending on the value of the **Actuator orientation** parameter.

## Basic Assumptions and Limitations

- No loading, such as inertia, friction, hydraulic force, and so on, is taken into account. The only force considered is a spring force.
- No flow consumption associated with the piston motion, leakage, or fluid compressibility is taken into account.

## Parameters

### Piston area

Effective piston area. The default value is  $2e-4 \text{ m}^2$ .

### Preload force

Spring preload force. The default value is 20 N.

### Full stroke force

Force necessary to move the piston to maximum stroke. The default value is 70 N.

### Piston stroke

Piston stroke. The default value is  $5e-3 \text{ m}$ .

### Actuator orientation

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it moves the piston in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port X moves the piston in the negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

## Ports

The block has the following ports:

X

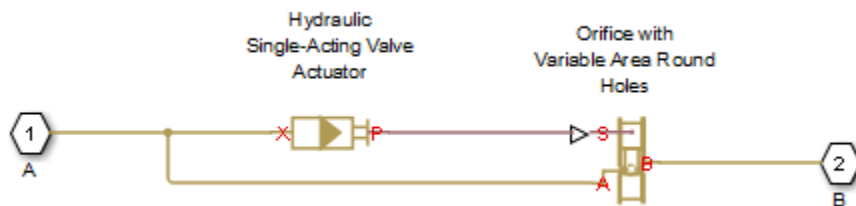
Hydraulic conserving port associated with the valve chamber.

P

Physical signal port that outputs piston displacement.

## Examples

The following example shows a model of a pressure-relief valve built using the Hydraulic Single-Acting Valve Actuator and Orifice with Variable Area Round Holes blocks.



## Version History

Introduced in R2007a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

2-Position Valve Actuator | 3-Position Valve Actuator | Hydraulic Double-Acting Valve Actuator | Proportional and Servo-Valve Actuator

## Hydraulically Operated Remote Control Valve

Normally closed or normally open hydraulically operated remote control valve

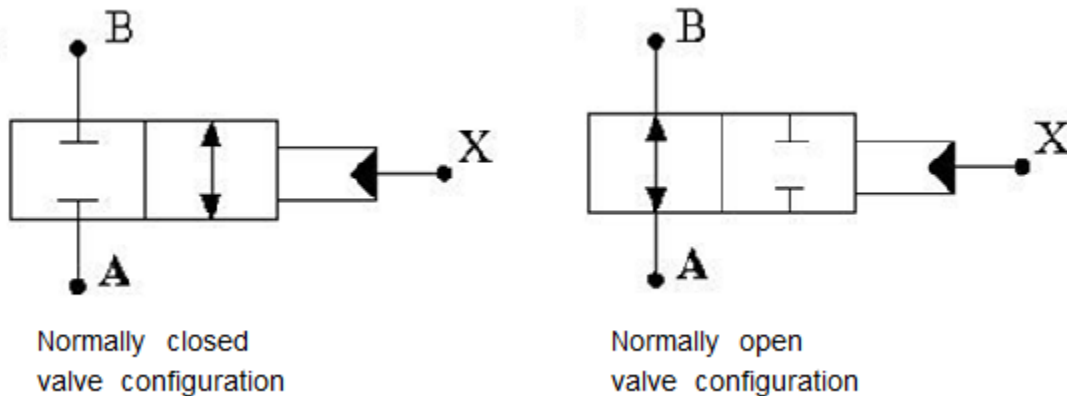


### Library

Directional Valves

### Description

The Hydraulically Operated Remote Control Valve block represents a hydraulically operated remote control valve as a data-sheet-based model, meaning that most of the model parameters are generally available in catalogs or manufacturer data sheets. Hydraulically operated remote control valves are widely used in hydraulic systems as hydraulic switches, unloading and sequencing valves. You can also use them as pressure-relief and pressure-reducing valves. The block covers both the normally closed and normally open configurations, shown in the following figure.

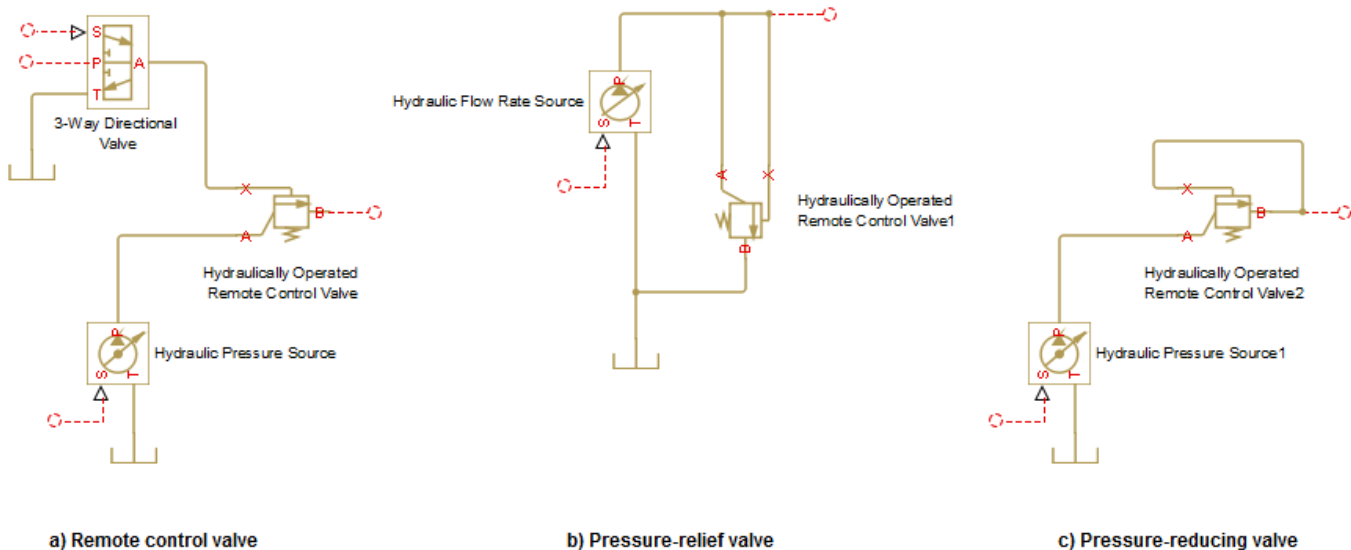


The valve opens (closes) by the pilot pressure. The valve control member remains in its initial position as long as the pilot pressure is lower than the cracking pressure. When cracking pressure is reached, the valve control member (spool, ball, poppet, and so on) is forced off its seat and starts opening the normally closed valve, or closing the normally open valve. The control member displacement is directly proportional to pilot pressure. The member reaches its maximum displacement after the pilot pressure becomes equal or greater than the preset maximum value. The valve maximum area, cracking pressure, and maximum pressure are the key parameters of the block. These three parameters are usually provided in catalogs or data sheets.

In addition to the maximum area, the leakage area is also required to characterize the valve. The main purpose of the parameter is not to account for possible leakage, even though this is also important, but to maintain numerical integrity of the circuit by preventing a portion of the system

from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause failure of computation. Therefore, the parameter value must be greater than zero.

Schematic fragments in the next illustration show some typical valve applications: remote control valve (a), pressure-relief valve (b), and pressure-reducing valve (c).



a) Remote control valve

b) Pressure-relief valve

c) Pressure-reducing valve

The flow rate through the orifice is proportional to the orifice opening and the pressure differential across the orifice.

By default, the block does not include valve opening dynamics, and the valve sets its opening area directly as a function of pressure:

$$A = A(p)$$

Adding valve opening dynamics provides continuous behavior that is more physically realistic, and is particularly helpful in situations with rapid valve opening and closing. The pressure-dependent orifice passage area  $A(p)$  in the block equations then becomes the steady-state area, and the instantaneous orifice passage area in the flow equation is determined as follows:

$$A(t = 0) = A_{init}$$

$$\frac{dA}{dt} = \frac{A(p) - A}{\tau}$$

In either case, the flow rate through the valve is determined according to the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

For the normally closed valve, the instantaneous orifice passage area  $A(p)$  is computed with the equations:

$$A(p) = \begin{cases} A_{leak} & \text{for } p_p \leq p_{crack} \\ A_{leak} + gain \cdot (p_p - p_{crack}) & \text{for } p_{crack} < p_p < p_{max} \\ A_{max} & \text{for } p_p \geq p_{max} \end{cases}$$

For the normally open valve, the equations are similar:

$$A(p) = \begin{cases} A_{max} & \text{for } p_p \leq p_{crack} \\ A_{max} - gain \cdot (p_p - p_{crack}) & \text{for } p_{crack} < p_p < p_{max} \\ A_{leak} & \text{for } p_p \geq p_{max} \end{cases}$$

The rest of the equations apply to both valve configurations:

$$gain = \frac{A_{max} - A_{leak}}{p_{max} - p_{crack}}$$

$$\Delta p = p_A - p_B,$$

where

$q$	Flow rate through the valve
$p$	Pressure differential across the valve
$p_A, p_B$	Gauge pressures at the block terminals
$p_p$	Gage pressure at the pilot terminal
$C_D$	Flow discharge coefficient
$\rho$	Fluid density
$\tau$	Time constant for the first order response of the valve opening
$t$	Time
$A$	Instantaneous orifice passage area
$A(p)$	Pressure-dependent orifice passage area
$A_{init}$	Initial open area of the valve
$A_{max}$	Fully open valve passage area
$A_{leak}$	Closed valve leakage area
$p_{crack}$	Valve cracking pressure
$p_{max}$	Pilot pressure to shift the control member to its maximum
$p_{cr}$	Minimum pressure for turbulent flow, when the block transitions from laminar to turbulent regime

The minimum pressure for turbulent flow,  $p_{cr}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = (p_{avg} + p_{atm})(1 - B_{lam})$$

$$p_{avg} = (p_A + p_B)/2$$

where

$p_{avg}$	Average pressure between the block terminals
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Orifice hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

Connections A and B are hydraulic conserving ports associated with the inlet and the outlet of the valve. Connection X is the pilot port, which is a hydraulic conserving port that provides the pilot pressure. The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ .

## Basic Assumptions and Limitations

- Control member displacement is linearly proportional to pilot pressure.
- No flow consumption is associated with the pilot chamber.
- No loading on the valve, such as inertia, friction, spring, and so on, is considered.

## Parameters

### Valve type

Select the valve configuration: Normally closed valve or Normally open valve. The default is Normally closed valve.

### Maximum passage area

Valve passage maximum cross-sectional area. The default value is  $1e-4 \text{ m}^2$ .

### Cracking pressure

Pressure level at which the valve control member is forced off its seat and starts to either open or close the valve, depending on the valve type. The default value is  $3e4 \text{ Pa}$ .

### Maximum control member displacement pressure

Pilot pressure at which the valve control member shifts to its maximum displacement and remains there until the pressure falls below this level. Its value must be higher than the cracking pressure. The default value is  $1.2e5 \text{ Pa}$ .

**Flow discharge coefficient**

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

**Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Opening dynamics**

Select one of the following options:

- **Do not include valve opening dynamics** — The valve sets its orifice passage area directly as a function of pressure. If the area changes instantaneously, so does the flow equation. This is the default.
- **Include valve opening dynamics** — Provide continuous behavior that is more physically realistic, by adding a first-order lag during valve opening and closing. Use this option in hydraulic simulations with the local solver for real-time simulation. This option is also helpful if you are interested in valve opening dynamics in variable step simulations.

**Opening time constant**

The time constant for the first order response of the valve opening. This parameter is available only if **Opening dynamics** is set to **Include valve opening dynamics**. The default value is 0.1 s.

**Initial area**

The initial opening area of the valve. This parameter is available only if **Opening dynamics** is set to **Include valve opening dynamics**. The default value is  $1e-12 \text{ m}^2$ .



## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Valve type**
- **Opening dynamics**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Opening dynamics** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

X

Hydraulic conserving port that acts as the control port and provides the pilot pressure.

## Version History

**Introduced in R2012b**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Pressure Reducing Valve | Pressure Relief Valve

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Interface (2P-G)

Two-phase fluid and gas network interface

**Library:** Simscape / Fluids / Fluid Network Interfaces



### Description

The Interface (2P-G) block represents a flow connection between a two-phase fluid network and a gas network. Pressure, temperature, and mass flow rate are equal at the interface. The block does not transfer the fluid properties of each fluid network across the interface. To conserve fluid properties, ensure that the Gas Properties (G) block and the Two-Phase Fluid Properties (2P) block have corresponding settings.

The fluid at the **2P** port must remain superheated. You can use the **Two-phase fluid superheated vapor check** parameter to choose what action the block performs if the fluid does not meet this condition.

### Mass and Momentum Balance

The block conserves mass such that

$$\dot{m}_{2P} + \dot{m}_G = 0,$$

where:

- $\dot{m}_G$  is the mass flow rate into port **G**.
- $\dot{m}_{2P}$  is the mass flow rate into port **2P**.

The port pressures are equal:

$$P_G = P_{2P}.$$

### Energy Balance

The temperature is constant between the two fluid ports. The block calculates the energy balance over the interface as

$$\Phi_G + \Phi_{2P} = \dot{m}_G \left( h_G + \frac{w_G^2}{2} \right) + \dot{m}_{2P} \left( h_{2P} + \frac{w_{2P}^2}{2} \right),$$

where:

- $\Phi_G$  is the energy flow rate into port **G**.
- $\Phi_{2P}$  is the energy flow rate into port **2P**.
- $h_G$  is the specific enthalpy at port **G**.
- $h_{2P}$  is the specific enthalpy at port **2P**.
- $v_G$  is the specific volume at port **G**.

- $v_{2P}$  is the specific volume at port **2P**.
- $w_G$  is the flow velocity at port **G** such that

$$w_G = \frac{\dot{m}_G v_G}{S},$$

where  $S$  is the value of the **Cross-sectional area at ports 2P and G** parameter.

- $w_{2P}$  is the flow velocity at port **2P** such that

$$w_{2P} = \frac{\dot{m}_{2P} v_{2P}}{S}.$$

## Ports

### Conserving

#### **2P — Two-phase port**

two-phase fluid

Two-phase fluid conserving port associated with the two-phase fluid at the interface.

#### **G — Fluid port**

gas

Gas conserving port associated with the gas at the interface.

## Parameters

#### **Cross-sectional area at ports 2P and G — Port area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the two-phase fluid and gas ports.

#### **Two-phase fluid superheated vapor check — Two-phase fluid superheated conditions check**

None (default) | Warning | Error

Action to perform when the fluid at port **2P** does not meet superheated conditions.

## Version History

Introduced in R2021a

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Interface (2P-TL) | Interface (2P-MA) | Interface (G-MA)

## Interface (2P-MA)

Two-phase fluid and moist air network interface

**Library:** Simscape / Fluids / Fluid Network Interfaces



### Description

The Interface (2P-MA) block represents a flow connection between a two-phase fluid network and moist air network. Pressure, temperature, and mass flow rate are equal at the interface. The block does not transfer the fluid properties of each fluid network across the interface. When moist air leaves port **MA**, the block assigns the values of the **Interface relative humidity** and **Interface trace gas mass fraction** parameters to the signal. However, when moist air enters port **MA**, the block retains the upstream values.

You can choose whether to maintain constant moisture and trace gas amounts at the interface or to specify them using the **W** and **TG** ports respectively. The fluid at the **2P** port must remain superheated. You can use the **Two-phase fluid superheated vapor check** parameter to choose what action the block performs if the fluid does not meet this condition.

### Equations

The block conserves mass such that

$$\dot{m}_{2P} + \dot{m}_{MA} = 0,$$

where:

- $\dot{m}_{2P}$  is the mass flow rate into port **2P**.
- $\dot{m}_{MA}$  is the mass flow rate into port **MA**.

The block maintains equal port pressures and temperatures such that

$$p_{2P} = p_{MA}$$

$$T_{2P} = T_{MA}$$

The block calculates the energy balance over the interface as

$$\Phi_{2P} + \Phi_{MA} = \dot{m}_{2P} \left( h_{2P} + \frac{w_{2P}^2}{2} \right) + \dot{m}_{MA} \left( h_{MA} + \frac{w_{MA}^2}{2} \right),$$

where:

- $\Phi_{2P}$  is the energy flow rate into port **2P**.
- $\Phi_{MA}$  is the energy flow rate into port **MA**.
- $h_{2P}$  is the specific enthalpy at port **2P**.
- $h_{MA}$  is the specific enthalpy at port **MA**.
- $v_{2P}$  is the specific volume at port **2P**.

- $v_{MA}$  is the specific volume at port **MA**.
- $w_{2P}$  is the flow velocity at port **2P**.
- $w_{MA}$  is the flow velocity at port **MA**.

For a given cross-sectional area,  $S$ , the block defines  $w_{2P}$  as

$$w_{2P} = \frac{\dot{m}_{2P} v_{2P}}{S}.$$

and  $w_{MA}$  as

$$w_{MA} = \frac{\dot{m}_{MA} v_{MA}}{S},$$

where

$$v_{MA} = \frac{R_I T_{MA}}{p_{MA}}.$$

You specify  $S$  using the **Cross-sectional area at ports 2P and MA** parameter. The block computes the specific gas constant of the interface mixture,  $R_I$ , as a function of the fluid on either side such that

$$R_I = f(R_A, R_W, R_G, x_{WI}, x_{GI}),$$

where:

- $R_A$  is the dry air specific gas constant.
- $R_W$  is the water vapor specific gas constant.
- $R_G$  is the trace gas specific gas constant.
- $x_{WI}$  is the interface specific humidity. When the flow exits port **MA**, the block assigns this value based on the value of the **Interface relative humidity** parameter or the input that you supply at port **W**.
- $x_{GI}$  is the interface trace gas mass fraction. When the flow exits port **MA**, the block assigns this value based on the value of the **Interface trace gas mass fraction** parameter or the input that you supply at port **TG**.

## Ports

### Input

#### **W – Moisture, unitless**

physical signal

Physical signal port associated with the moisture content at the interface.

#### **Dependencies**

To enable this port, set **Moisture and trace gas specification** to **Controlled**.

#### **TG – Trace gas, unitless**

physical signal

Physical signal port associated with the trace gas at the interface.

**Dependencies**

To enable this port, set **Moisture and trace gas specification** to **Controlled**.

**Conserving****2P — Two-phase port**

two-phase fluid

Two-phase fluid conserving port associated with the two-phase fluid at the interface.

**MA — Moist air port**

moist air

Moist air conserving port associated with the moist air at the interface.

**Parameters****Moisture and trace gas specification — Interface moisture and trace gas control option**

Constant (default) | Controlled

Option to maintain a constant interface or to specify the moisture and trace gas amounts via physical signal ports. When you select **Controlled**, the block exposes the **W** and **TG** ports.

**Interface moisture specification — Moisture parameterization option**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Whether to calculate moisture using relative humidity, specific humidity, mole fraction, or humidity ratio.

**Interface relative humidity — Relative humidity at interface**

0.5 (default) | positive scalar

Relative humidity at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to **Constant** and **Moisture specification** to **Relative humidity**.

**Interface specific humidity — Specific humidity at interface**

0.01 (default) | positive scalar

Specific humidity at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to **Constant** and **Moisture specification** to **Specific humidity**.

**Interface water vapor mole fraction — Water vapor mole fraction at interface**

0.01 (default) | positive scalar

Water vapor mole fraction at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Mole fraction.

**Interface humidity ratio — Humidity ratio at interface**

0.01 (default) | positive scalar

Humidity ratio at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Humidity ratio.

**Interface trace gas specification — Trace gas parameterization**

Mass fraction (default) | Mole fraction

Whether to parameterize the trace gas at the interface using mass fraction or mole fraction.

**Interface trace gas mass fraction — Trace gas mass fraction at interface**

0.001 (default) | positive scalar

Mass fraction of trace gas at the interface.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Interface trace gas specification** to Mass fraction.

**Interface trace gas mole fraction — Trace gas mole fraction at interface**

0.001 (default) | positive scalar

Mole fraction of trace gas at the interface.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Interface trace gas specification** to Mole fraction.

**Relative humidity at saturation — Saturation point relative humidity**

1 (default) | positive scalar

Relative humidity at the point of saturation.

**Cross-sectional area at ports 2P and MA — Port area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the two-phase fluid and moist air ports.

**Two-phase fluid superheated vapor check — Two-phase fluid superheated conditions check**

None (default) | Warning | Error

Action to perform when the fluid at the interface does not meet superheated conditions.

**Inputs outside valid range — Option to monitor or control invalid inputs**

Limit to valid values (default) | Warn and limit to valid values | Error

Monitor or control invalid inputs. When you select **Limit to valid values**, the block saturates the inputs within the bounds. You can choose to have the block issue a warning when it limits the inputs by selecting **Warn and limit to valid values**, or you can stop the simulation when the block receives invalid inputs by selecting **Error**.

**Dependencies**

To enable this parameter, set **Interface type** to **Controlled**.

## Version History

Introduced in R2022a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Interface (2P-G) | Interface (2P-TL) | Interface (G-MA)



## Interface (2P-TL)

Two-phase fluid and thermal liquid network interface

**Library:** Simscape / Fluids / Fluid Network Interfaces



### Description

The Interface (2P-TL) block represents a flow connection between a two-phase fluid network and a thermal liquid network. Pressure, temperature, and mass flow rate are equal at the interface. The block does not transfer the fluid properties of each fluid network across the interface. To conserve fluid properties, ensure that the Thermal Liquid Properties (TL) block and the Two-Phase Fluid Properties (2P) block have the same settings.

The fluid at the **2P** port must remain subcooled. You can use the **Two-phase fluid subcooled liquid check** parameter to choose what action the block performs if the fluid does not meet this condition.

### Mass and Momentum Balance

The block conserves mass such that

$$\dot{m}_{TL} + \dot{m}_{2P} = 0,$$

where:

- $\dot{m}_{TL}$  is the mass flow rate into port **TL**.
- $\dot{m}_{2P}$  is the mass flow rate into port **2P**.

The port pressures are equal:

$$P_{TL} = P_{2P}.$$

### Energy Balance

The temperature is constant between the two fluid ports. The block calculates the energy balance over the interface as

$$\Phi_{TL} + \Phi_{2P} = \dot{m}_{TL} \left( u_{TL} + p_{TL} v_{TL} + \frac{w_{TL}^2}{2} \right) + \dot{m}_{2P} \left( u_{2P} + p_{2P} v_{2P} + \frac{w_{2P}^2}{2} \right),$$

where:

- $\Phi_{TL}$  is the energy flow rate into port **TL**.
- $\Phi_{2P}$  is the energy flow rate into port **2P**.
- $h_{TL}$  is the specific internal energy at port **TL**.
- $h_{2P}$  is the specific internal energy at port **2P**.
- $v_{TL}$  is the specific volume at port **TL**.

- $v_{2P}$  is the specific volume at port **2P**.
- $w_{TL}$  is the flow velocity at port **TL**

$$w_{TL} = \frac{\dot{m}_{TL}v_{TL}}{S},$$

- $w_{2P}$  is the flow velocity at port **2P**

$$w_{2P} = \frac{\dot{m}_{2P}v_{2P}}{S}.$$

- $S$  is the value of the **Cross-sectional area at ports 2P and TL** parameter.

## Ports

### Conserving

#### **2P — Two-phase port**

two-phase fluid

Two-phase fluid conserving port associated with the two-phase fluid at the interface.

#### **TL — Fluid port**

thermal liquid

Thermal liquid conserving port associated with the thermal liquid at the interface.

## Parameters

#### **Cross-sectional area at ports 2P and TL — Port area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the thermal liquid and two-phase fluid ports.

#### **Two-phase fluid subcooled liquid check — Two-phase fluid subcooled conditions check**

None (default) | Warning | Error

Action to perform when the fluid at port **2P** does not meet subcooled conditions.

## Version History

Introduced in R2021a

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Interface (2P-G) | Interface (TL-IL) | Interface (2P-MA)

## Interface (G-MA)

Gas and moist air network interface

**Library:** Simscape / Fluids / Fluid Network Interfaces



### Description

The Interface (G-MA) block represents a flow connection between a gas network and moist air network. Pressure, temperature, and mass flow rate are equal at the interface. The block does not transfer the fluid properties of each fluid network across the interface. To conserve fluid properties, ensure that the Gas Properties (G) block and the Moist Air Properties (MA) block have the same settings. When moist air leaves port **MA**, the block assigns the values of the **Interface specific humidity** and **Interface trace gas mass fraction** parameters to the signal. However, when moist air enters port **MA**, the block retains the upstream values.

You can choose whether to maintain constant moisture and trace gas amounts at the interface or to specify them using the **W** and **TG** ports, respectively.

### Mass and Momentum Balance

The block conserves mass such that

$$\dot{m}_G + \dot{m}_{MA} = 0,$$

where:

- $\dot{m}_G$  is the mass flow rate into port **G**.
- $\dot{m}_{MA}$  is the mass flow rate into port **MA**.

The block maintains equal port pressures and temperatures such that

$$\begin{aligned} p_G &= p_{MA} \\ T_G &= T_{MA} \end{aligned}$$

### Energy Balance

The block calculates the energy balance over the interface as

$$\Phi_G + \Phi_{MA} = \dot{m}_G \left( h_G + \frac{w_G^2}{2} \right) + \dot{m}_{MA} \left( h_{MA} + \frac{w_{MA}^2}{2} \right),$$

where:

- $\Phi_G$  is the energy flow rate into port **G**.
- $\Phi_{MA}$  is the energy flow rate into port **MA**.
- $h_G$  is the specific enthalpy at port **G**.
- $h_{MA}$  is the specific enthalpy at port **MA**.

- $v_G$  is the specific volume at port **G**.
- $v_{MA}$  is the specific volume at port **MA**.
- $w_G$  is the flow velocity at port **G**.
- $w_{MA}$  is the flow velocity at port **MA**.

For a given cross-sectional area,  $S$ , the block defines  $w_G$  as

$$w_G = \frac{\dot{m}_G v_G}{S},$$

and  $w_{MA}$  as

$$w_{MA} = \frac{\dot{m}_{MA} v_{MA}}{S},$$

where:

$$v_{MA} = \frac{R_I T_{MA}}{p_{MA}}.$$

The specific gas constant of the mixture at the interface is a function of the fluid on either side such that

$$R_I = f(R_A, R_W, R_G, x_{WI}, x_{GI}),$$

where:

- $R_A$  is the dry air specific gas constant.
- $R_W$  is the water vapor specific gas constant.
- $R_G$  is the trace gas specific gas constant.
- $x_{WI}$  is the interface specific humidity. The upstream moist air network assigns this value when flow enters port **MA**. When the flow exits port **MA**, the block assigns this value based on the value of the **Interface relative humidity** parameter or the input that you supply at port **W**.
- $x_{GI}$  is the interface trace gas mass fraction. The upstream moist air network assigns this value when flow enters port **MA**. When the flow exits port **MA**, the block assigns this value based on the value of the **Interface trace gas mass fraction** parameter or the input that you supply at port **TG**.

## Ports

### Conserving

#### **G – Fluid port**

gas

Gas conserving port associated with the gas at the interface.

#### **MA – Moist air port**

moist air

Moist air conserving port associated with the moist air at the interface.

**W – Moisture**

physical signal

Physical signal port associated with the moisture content at the interface.

**Dependencies**

To enable this port, set **Interface type** to Controlled.

**TG – Trace gas**

physical signal

Physical signal port associated with the trace gasses at the interface.

**Dependencies**

To enable this port, set **Interface type** to Controlled.

**Parameters****Moisture and trace gas specification – Interface moisture control option**

Constant (default) | Controlled

Option to maintain a constant interface or to specify the moisture and trace gas amounts via physical signal ports. When you select Controlled, the block exposes the **W** and **TG** ports.

**Interface moisture specification – Moisture parameterization option**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Whether to calculate moisture using relative humidity, specific humidity, mole fraction, or humidity ratio.

**Interface relative humidity – Relative humidity at interface**

0.5 (default) | positive scalar

Relative humidity at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Relative humidity.

**Interface specific humidity – Specific humidity at interface**

0.01 (default) | positive scalar

Specific humidity at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Specific humidity.

**Interface water vapor mole fraction – Water vapor mole fraction at interface**

0.01 (default) | positive scalar

Water vapor mole fraction at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Mole fraction.

**Interface humidity ratio — Humidity ratio at interface**

0.01 (default) | positive scalar

Humidity ratio at the interface. The block uses this value to calculate the moisture.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Moisture specification** to Humidity ratio.

**Interface trace gas specification — Trace gas parameterization**

Mass fraction (default) | Mole fraction

Whether to parameterize the trace gas at the interface using mass fraction or mole fraction.

**Interface trace gas mass fraction — Trace gas mass fraction at the interface**

0.001 (default) | positive scalar

Mass fraction of trace gas at the interface.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Interface trace gas specification** to Mass fraction.

**Interface trace gas mole fraction — Trace gas mole fraction at the interface**

0.001 (default) | positive scalar

Mole fraction of trace gas at the interface.

**Dependencies**

To enable this parameter, set **Interface type** to Constant and **Interface trace gas specification** to Mole fraction.

**Relative humidity at saturation — Saturation point relative humidity**

1 (default) | positive scalar

Relative humidity at the point of saturation.

**Cross-sectional area at ports G and MA — Port area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the gas and moist air ports.

**Inputs outside valid range — Option to monitor or control invalid inputs**

Limit to valid values (default) | Warn and limit to valid values | Error

Monitor or control invalid inputs. When you select **Limit to valid values**, the block saturates the inputs within the bounds. You can choose to have the block issue a warning when it limits the inputs by selecting **Warn and limit to valid values**, or you can stop the simulation when the block receives invalid inputs by selecting **Error**.

**Dependencies**

To enable this parameter, set **Interface type** to Controlled.

**Version History**

Introduced in R2022a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

[Interface \(2P-G\)](#) | [Interface \(2P-MA\)](#)

## Interface (TL-IL)

Connection between thermal and isothermal networks

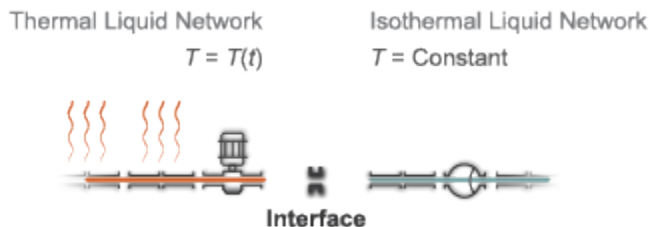
**Library:** Simscape / Fluids / Fluid Network Interfaces



### Description

The Interface block is a connector between thermal and isothermal fluid networks. The fluid mass flow rate and pressure are matched between the networks, but fluid properties are not passed between the two networks. To maintain fluid properties between the thermal and isothermal components of your model, connect an Isothermal Liquid Predefined Properties (IL) block with the desired properties to the isothermal network side.

You can connect Thermal Liquid library blocks with Isothermal Liquid library or Hydraulics (Isothermal) library blocks. The temperature set in the isothermal system can either be **Constant** or **Controlled**. In the case of a **Controlled** temperature system, the isothermal network temperature is set by the thermal liquid temperature. In the **Constant** temperature setting, you specify the isothermal network temperature directly.



### Thermal Liquid - Isothermal Liquid

When **Fluids domain interface** is set to Thermal Liquid (TL) - Isothermal Liquid (IL), the mass flow rate is conserved over the two mass-flow-rate-based networks:

$$\dot{m}_{TL} + \dot{m}_{IL} = 0,$$

where:

- $\dot{m}_{TL}$  is the mass flow rate at the thermal liquid interface.
- $\dot{m}_{IL}$  is the mass flow rate at the isothermal liquid interface.

The fluid absolute pressure is maintained between the thermal, internal, and isothermal sections of the Interface block:

$$p_{TL} = p_{IL}.$$



## Thermal Liquid - Hydraulics (Isothermal)

The Hydraulics (Isothermal) Liquid library is based on volumetric flow rate. To maintain flow continuity between both sides of the interface, the volumetric flow rate is multiplied by the fluid density:

$$\dot{m}_{TL} + q_H \rho_H = 0,$$

where:

- $q_H$  is the Hydraulics (Isothermal) volumetric flow rate.
- $\rho_H$  is the local Hydraulics (Isothermal) fluid density.

The Hydraulics (Isothermal) Liquid library blocks are constructed in terms of gauge pressures. Pressure is converted to absolute pressure internally to match the thermal network pressure:

$$p_H + p_{atm} = p_{TL}.$$

## Ports

### Conserving

#### TL – Liquid port

thermal liquid

Entry or exit port to the thermal liquid network.

#### IL – Liquid port

isothermal liquid

Entry or exit port to the isothermal liquid network.

### Dependencies

To enable this port, set **Fluids domain interface** to Thermal Liquid (TL) - Isothermal Liquid (IL).

#### H – Liquid port

isothermal liquid

Entry or exit port to the hydraulics (isothermal) liquid network.

### Dependencies

To enable this port, set **Fluids domain interface** to Thermal Liquid (TL) - Hydraulic (H).

## Parameters

### Fluids domain interface – Connecting library types

Thermal Liquid (TL) - Isothermal Liquid (IL) (default) | Thermal Liquid (TL) - Hydraulic (H)

Specifies the connecting library types.

**Temperature specification — Isothermal network temperature**

Constant (default) | Controlled

Sets the isothermal network temperature. In the Constant setting, you can specify the isothermal network temperature in the **Hydraulic temperature** parameter. In the Controlled setting, the temperature in the isothermal network is set by the thermal network.

**Interface temperature — Isothermal network temperature**

293.15 K (default) | positive scalar

Specifies the fluid temperature transmitted from the thermal liquid network to the hydraulic or isothermal liquid network.

**Dependencies**

To enable this parameter, set **Temperature specification** to Constant.

**Cross-sectional area at port TL — Thermal liquid port area**0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the thermal liquid port.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Interface (H-IL) | Isothermal Liquid Predefined Properties (IL) | Isothermal Liquid Properties (IL)

# Jet Pump

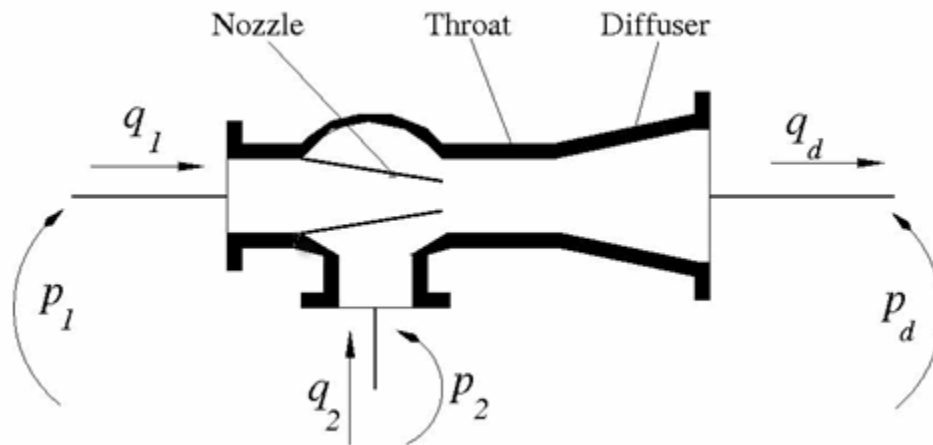
Jet liquid-liquid pump

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Jet Pump block represents a jet liquid-liquid pump consisting of a nozzle, throat, and diffuser, as shown in this illustration.



The model is based on these equations, described in [1]:

$$q_1 = \frac{A_n}{\sqrt{1 + K_n}} \sqrt{\frac{2}{\rho} (p_1 - p_0)} \tag{1-8}$$

$$q_2 = \frac{A_n \cdot c}{\sqrt{1 + K_{en}}} \sqrt{\frac{2}{\rho} (p_2 - p_0)} \tag{1-9}$$

$$p_d - p_0 = Z b^2 \left( \frac{2}{b} + \frac{2}{1-b} M^2 - (1 + M)^2 \cdot (1 + K_{th} + K_{di} + a^2) \right) \tag{1-10}$$

$$b = \frac{A_n}{A_{th}}$$

$$c = \frac{1 - b}{b}$$

$$Z = \rho \frac{V_n^2}{2} = \rho \frac{q_1^2}{2 A_n^2}$$

$$M = \frac{q_2}{q_1}$$

where:

$q_1$	Primary flow rate pumped through the nozzle
$q_2$	Secondary flow rate
$q_d$	Output flow rate
$p_1$	Pressure at the nozzle inlet
$p_2$	Pressure at the secondary flow rate inlet
$p_0$	Pressure at the throat inlet
$p_d$	Pressure at the pump outlet
$A_n$	Nozzle area
$A_{th}$	Throat area
$a$	Diffuser area ratio, $A_{th} / A_d$
$A_d$	Diffuser outlet area
$K_n$	Nozzle hydraulic loss coefficient
$K_{en}$	Throat entry hydraulic loss coefficient
$K_{th}$	Throat hydraulic loss coefficient
$K_{di}$	Diffuser hydraulic loss coefficient
$\rho$	Fluid density

Equation 1 on page 1-1181 describes the nozzle, Equation 2 on page 1-1181 describes the throat entry, and Equation 3 on page 1-1181 describes the combination of the throat and the diffuser. The equations correspond to a standard configuration of the pump, where all the longitudinal dimensions conform to established, empirically determined values. For more details, see [1].

The pump parameters are closely related to each other, and the methodology described in [1] is recommended to determine their initial values.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- The model is based on the one-dimensional theory.
- The primary and secondary flows enter the mixing throat with uniform velocity distribution, and the mixed flow leaves the diffuser with uniform velocity distribution.

- The fluid in the primary and secondary flows is the same.
- The fluid is assumed to be incompressible and containing no gas.

## Ports

### Conserving

#### **A — Nozzle entry**

hydraulic

Hydraulic conserving port associated with the nozzle entry. The nozzle is the primary flow entry.

#### **S — Pump suction**

hydraulic

Hydraulic conserving port associated with the pump suction. The pump suction is the secondary flow entry.

#### **P — Pump outlet**

hydraulic

Hydraulic conserving port associated with the pump outlet.

#### **N — Internal nonvisible port associated with throat entry section of pump**

hydraulic

Internal hydraulic conserving port associated with the throat entry section of the pump. This port is not visible on the block icon. You can view the variables associated with the port by logging the simulation data. For more information, see “Data Logging”.

## Parameters

#### **Nozzle area — Cross-sectional area of nozzle**

1 cm<sup>2</sup> (default) | positive scalar

Cross-sectional area of the nozzle.

#### **Throat area — Cross-sectional area of throat**

4 cm<sup>2</sup> (default) | positive scalar

Cross-sectional area of the throat. The throat area is usually two to four times larger than the nozzle area.

#### **Diffuser inlet/outlet area ratio — Ratio between inlet and outlet diffuser areas**

0.224 (default) | positive scalar

Ratio between the inlet and outlet diffuser areas. For a standard pump with a 5°-7° included-angle diffuser, the ratio is close to 0.2.

#### **Nozzle loss coefficient — Hydraulic friction loss coefficient in nozzle**

0.05 (default) | positive scalar

Hydraulic friction loss coefficient in the nozzle.

**Throat entry loss coefficient – Hydraulic friction loss coefficient in throat entry**

0.005 (default) | positive scalar

Hydraulic friction loss coefficient in the throat entry.

**Throat loss coefficient – Hydraulic friction loss coefficient in throat**

0.1 (default) | positive scalar

Hydraulic friction loss coefficient in the throat.

**Diffuser loss coefficient – Hydraulic friction loss coefficient in diffuser**

0.1 (default) | positive scalar

Hydraulic friction loss coefficient in the diffuser.

## Version History

Introduced in R2010b

## References

[1] I.J. Karassic, J.P. Messina, P. Cooper, C.C. Heald, *Pump Handbook*, Fourth edition, McGraw-Hill, NY, 2008

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Centrifugal Pump | Fixed-Displacement Pump | Variable-Displacement Pressure-Compensated Pump | Variable-Displacement Pump

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Jet Pump (IL)

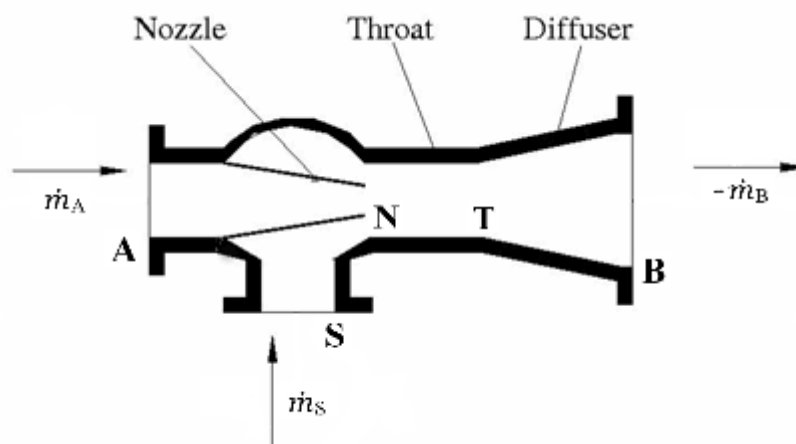
Liquid-liquid jet pump in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors



### Description

The Jet Pump (IL) block models a liquid-liquid jet pump in an isothermal liquid network with the same motive and suction fluids. The motive enters the primary nozzle at port **A**, which draws in the suction fluid through input port **S**. After mixing in the throat, the combined flow expands through the diffuser and is discharged at port **B**. The total pressure change over the pump is the sum of the individual contributions of friction and area change in each section of the pump and momentum changes in the throat. The sign convention for the equations below correspond to positive flow into the throat.



### Jet Pump Schematic

#### Changes in Pressure Due to Area Changes

The mass flow rate is conserved in the pump:

$$\dot{m}_A + \dot{m}_S + \dot{m}_B = 0,$$

where  $\dot{m}_A$  is the mass flow rate through port **A**,  $\dot{m}_S$  is the mass flow rate through port **S**, and  $\dot{m}_B$  is the mass flow rate through port **B**.

Using mass conservation and the Bernoulli Principle, the area changes over the pump segments can be expressed in terms of pressure change. The pressure change associated with the nozzle is:

$$\Delta p_{a, \text{Nozzle}} = \frac{\dot{m}_A^2}{4\rho A_N^2},$$

or 0, whichever is greater. The formulation depends on:

- $A_N$ , the **Nozzle area**, taken at its widest section.
- $\rho$ , the fluid density.

It is assumed that the nozzle inlet is much larger than the nozzle outlet.

Although the geometry of a typical suction inlet is not shaped like a nozzle, it effectively experiences the same type of area reduction as it enters the throat around the nozzle outlet. This annulus is assumed to be much smaller than the suction inlet. The pressure change due to this area reduction is:

$$\Delta p_{a, Annulus} = \frac{\dot{m}_S}{4\rho(A_T - A_N)^2},$$

or 0, whichever is greater.  $A_T$  is the cross-sectional area of the throat. The pressure change over the diffuser expansion is:

$$\Delta p_{a, Diffuser} = -\frac{\dot{m}_B^2}{2\rho A_T^2}(1 - a^2),$$

where  $a$  is the **Diffuser inlet to outlet area ratio**.

---

**Reversed Flows** In the case of reversed flow, the effect of the nozzle area on pressure change is not modeled, and therefore flow traveling from the throat through the nozzle will not undergo any pressure gain. This ensures the numerical stability of the block during simulation of reversed flows.

---

### Changes in Pressure Due to Mixing

Mixing between the motive and suction flows occurs in the throat. This change in momentum is associated with a change in pressure:

$$\Delta p_{mixing} = \frac{\frac{\dot{m}_A^2}{b} + \frac{\dot{m}_S^2}{1-b} - \dot{m}_B^2}{\rho A_T},$$

where  $b$  is the **Nozzle to throat area ratio**, which is defined between the largest and smallest cross-sectional areas of the nozzle.

### Pressure Losses Due to Friction

The flow experiences losses due to friction in the nozzle, secondary suction inlet, throat, and diffuser. These losses are calculated based on a coefficient defined for each section and the area, or area ratio, between different sections of the pump. Note that friction incurs pressure losses, irrespective of flow direction. The pressure loss in the nozzle due to friction is:

$$\Delta p_{f, Nozzle} = K_N \frac{\dot{m}_A |\dot{m}_A|}{2\rho A_N^2},$$

where  $K_N$  is the **Primary flow nozzle loss coefficient**. The pressure loss due to friction in the suction flow through the annulus is:



$$\Delta p_{f, Annulus} = K_S \frac{\dot{m}_S |\dot{m}_S|}{2\rho(A_T - A_N)^2},$$

where  $K_S$  is the **Secondary flow entry loss coefficient**. The pressure loss in the throat due to friction is:

$$\Delta p_{f, Throat} = K_T \frac{\dot{m}_B |\dot{m}_B|}{2\rho A_T^2},$$

where  $K_T$  is the **Throat loss coefficient**. The pressure loss in the diffuser due to friction is:

$$\Delta p_{f, Diffuser} = K_D \frac{\dot{m}_B |\dot{m}_B|}{2\rho A_T^2},$$

where  $K_D$  is the **Diffuser loss coefficient**. Note that the sign corresponds to negative flow from the throat toward port **B**. Losses are defined for the regions of highest velocity in the flow. For this reason, the throat area, which is equal to the diffuser inlet area, is used in the diffuser loss equation.

### Saturation Pressure in the Nozzle

Cavitation occurs when a region of low pressure in the flow falls below the vapor saturation pressure. This creates pockets of vapor in the liquid and impedes any further increase in flow through the pump. You can model this flow rate limit by specifying a **Minimum nozzle pressure**, beyond which the fluid velocity will remain constant. The total pressure change over the pump depends on this pressure threshold at the nozzle outlet. Between the nozzle and the diffuser, the pressure change is either

$$p_B - p_N = \Delta p_{mixing} + \Delta p_{f, Throat} + \Delta p_{f, Diffuser} - \Delta p_{a, Diffuser}$$

or  $p_B - p_{N, \min}$ , whichever is smaller.

The total pressure change in the nozzle is:

$$p_A - p_N = \Delta p_{a, Nozzle} + \Delta p_{f, Nozzle}.$$

The total pressure change in the annulus is:

$$p_S - p_N = \Delta p_{a, Annulus} + \Delta p_{f, Annulus}.$$

### Assumptions and Limitations

- The motive and suction liquids are the same.
- Mixing in the throat is assumed to be uniform and complete.
- The nozzle inlet is much larger than the nozzle outlet, and the suction jet annulus is much smaller than the suction inlet.
- The change in pressure due to the nozzle is not modeled for reversed flows.
- Any effect of cavitation is modeled as a maximum limit on the flow rate in the throat.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Motive liquid inlet port.

#### **S – Liquid port**

isothermal liquid

Suction liquid inlet port.

#### **B – Liquid port**

isothermal liquid

Mixed fluid outlet port.

## Parameters

#### **Nozzle area – Nozzle inlet area**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the inlet nozzle at its widest section. The motive liquid enters the jet pump through the nozzle.

#### **Nozzle to throat area ratio – Nozzle outlet to throat area**

0.25 (default) | positive scalar

Characteristic ratio of the nozzle outlet and throat cross-sectional areas.

#### **Diffuser inlet to outlet area ratio – Diffuser geometry ratio**

0.25 (default) | positive scalar

Characteristic ratio of the diffuser inlet and outlet cross-sectional areas.

#### **Primary flow nozzle loss coefficient – Friction loss coefficient**

0.05 (default) | positive scalar

Characterizes the losses in pressure due to nozzle friction in the motive flow.

#### **Secondary flow entry loss coefficient – Friction loss coefficient**

0.005 (default) | positive scalar

Characterizes the losses in pressure in the suction flow due to the suction inlet friction.

#### **Throat loss coefficient – Friction loss coefficient**

0.1 (default) | positive scalar

Characterizes the losses in pressure in the mixture due to throat friction.

#### **Diffuser loss coefficient – Friction loss coefficient**

0.1 (default) | positive scalar

Characterizes the losses in pressure due in the mixed flow due to friction in the diffuser.

**Minimum nozzle pressure — Minimum pressure at the nozzle outlet**

0.1 Pa (default) | positive scalar

Sets the maximum allowed pressure change in the jet pump. If pressures at the nozzle exit fall below this value, the block simulates the effect of cavitation by restricting the fluid velocity to the velocity at the minimum nozzle pressure.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Fixed-Displacement Pump (IL) | Variable-Displacement Pump (IL) | Pressure-Compensated Pump (IL) | Centrifugal Pump (IL)

# Journal Bearing Pressure-Fed

Hydraulic portion of pressure-fed journal bearing

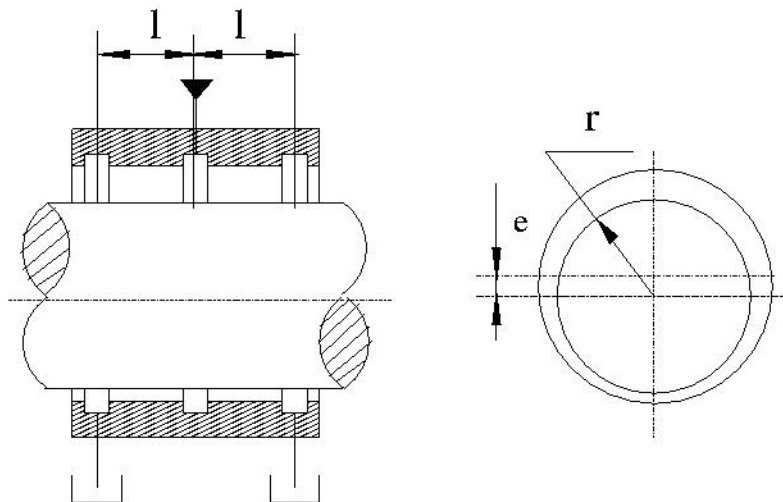


## Library

Orifices

## Description

The Journal Bearing Pressure-Fed block simulates the hydraulic portion of a pressure-fed journal bearing, shown in the following illustration.



The lubricant under pressure  $p$  is pumped into the circumferential groove at the center of the bearing. The groove divides the bearing into two half-bearings. The lubricant exits through the end grooves located at a distance  $l$  from the central groove. The model is intended to be used in lubrication system simulation to assess the flow consumption through the pressure-fed journal bearing. The flow regime is assumed to be laminar due to very small clearances between the journal and the bushing.

The flow rate is computed using the Hagen-Poiseuille equation (see [1] on page 1-1192):

$$q = \frac{\pi p r c^3}{3 \mu l} (1 + 1.5 \varepsilon^2)$$

where

$q$	Volumetric flow rate
$p$	Pressure differential across the bearing
$r$	Journal radius
$c$	Radial clearance at neutral position
$\mu$	Dynamic viscosity
$l$	Length of the half-bearing
$\varepsilon$	Relative eccentricity, $\varepsilon = e / r$
$e$	Eccentricity or journal deflection from the central position

The journal radial displacement, which controls the bearing eccentricity, is imported through the physical signal port J. Connections A and B are hydraulic conserving ports associated with the bearing inlet and outlet, respectively. The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port J increases the eccentricity and is limited to the radial clearance of the bearing.

## Basic Assumptions and Limitations

The flow regime is assumed to be laminar due to small clearances.

## Parameters

### Journal radius

The radius of the journal. The parameter must be positive. The default value is 0.05 m.

### Radial clearance

The radial clearance between the journal and the bushing at neutral position. The parameter must be positive. The default value is 2e-4 m.

### Bearing half-length

The length of the half-bearing, that is, the distance between each of the end grooves and the central groove. The parameter must be positive. The default value is 0.025 m.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the bearing inlet.

**B**

Hydraulic conserving port associated with the bearing outlet.

**J**

Physical signal port that controls the journal deflection.

## References

[1] Shigley, J., C. Mischke, and R. Budynas. *Mechanical Engineering Design*. New York: McGraw-Hill, 2004.

## Version History

Introduced in R2012b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

### Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Local Resistance

Hydraulic resistance specified by loss coefficient



## Library

Local Hydraulic Resistances

### Description

The Local Resistance block represents a generic local hydraulic resistance, such as a bend, elbow, fitting, filter, local change in the flow cross section, and so on. The pressure loss caused by resistance is computed based on the pressure loss coefficient, which is usually provided in catalogs, data sheets, or hydraulic textbooks. The pressure loss coefficient can be specified either as a constant, or by a table, in which it is tabulated versus Reynolds number.

The pressure drop between port **A** and port **B** is:

$$\Delta p = p_A - p_B,$$

where:

- $p$  is the pressure drop.
- $p_A$  is the gauge pressure at port **A**.
- $p_B$  is the gauge pressure at port **B**.

If the **Model parameterization** parameter is set to `By semi-empirical formulas`, the pressure drop is related to the volumetric flow rate by the expression:

$$q = A \sqrt{\frac{2}{K \cdot \rho}} \cdot \frac{p}{(p^2 + p_{Cr}^2)^{1/4}}$$

where:

- $q$  is the volumetric flow rate.
- $A$  is the flow area.
- $K$  is the pressure loss coefficient of the flow resistance.
- $\rho$  is the fluid density.
- $p_{Cr}$  is the minimum pressure for turbulent flow.

If the **Model parameterization** parameter is set to `By loss coefficient vs. Re table`, the pressure drop is related to the volumetric flow rate by the expression:

$$p = K(\text{Re}) \rho \frac{q|q|}{2A^2}$$

where  $K$  is now a function of the Reynolds number (Re). Its value is specified in the block dialog box in tabulated form against the Reynolds number:

$$Re = \frac{q \cdot D_H}{A \cdot \nu}$$

where:

- $D_H$  is the hydraulic diameter of the flow resistance:

$$D_H = \sqrt{\frac{4A}{\pi}}$$

- $\nu$  is the kinematic viscosity.

For a constant pressure loss coefficient, the minimum pressure for turbulent flow,  $p_{cr}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = (p_{avg} + p_{atm})(1 - B_{lam})$$

$$p_{avg} = (p_A + p_B)/2$$

where

$p_{avg}$	Average pressure between the block terminals
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = K \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{D_H} \right)^2$$

where

$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)
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The block provides two parameterizations:

- By **semi-empirical formulas** — The pressure loss coefficient is assumed to be constant for a specific flow direction. The flow regime can be either laminar or turbulent, depending on the Reynolds number.
- By **loss coefficient vs. Re table** — The pressure loss coefficient is specified as a function of the Reynolds number. The flow regime is assumed to be turbulent at all times. You must ensure that the loss coefficient data corresponds to this flow regime.

The resistance can be symmetrical or asymmetrical. In symmetrical resistances, the pressure loss practically does not depend on flow direction and one value of the coefficient is used for both the direct and reverse flow. For asymmetrical resistances, the separate coefficients are provided for each



flow direction. If the loss coefficient is specified by a table, the table must cover both the positive and the negative flow regions.

Connections A and B are conserving hydraulic ports associated with the block inlet and outlet, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure loss is determined as  $\Delta p = p_A - p_B$ .

## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- If you select parameterization by the table-specified relationship  $K=f(Re)$ , the flow is assumed to be completely turbulent.

## Parameters

### Parameters Tab

#### Resistance area

The smallest passage area. The default value is  $1e-4 \text{ m}^2$ .

#### Model parameterization

Select one of the following methods for specifying the pressure loss coefficient:

- **By semi-empirical formulas** — Provide a scalar value for the pressure loss coefficient. For asymmetrical resistances, you have to provide separate coefficients for direct and reverse flow. This is the default method.
- **By loss coefficient vs. Re table** — Provide tabulated data of loss coefficients and corresponding Reynolds numbers. The loss coefficient is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods. For asymmetrical resistances, the table must cover both the positive and the negative flow regions.

#### Pressure loss coefficient for direct flow

Loss coefficient for the direct flow (flowing from A to B). For simple ideal configurations, the value of the coefficient can be determined analytically, but in most cases its value is determined empirically and provided in textbooks and data sheets (for example, see [1] on page 1-1198). The default value is 2. This parameter is used if **Model parameterization** is set to **By semi-empirical formulas**.

### Pressure loss coefficient for reverse flow

Loss coefficient for the reverse flow (flowing from B to A). The parameter is similar to the loss coefficient for the direct flow and must be set to the same value if the resistance is symmetrical. The default value is 2. This parameter is used if **Model parameterization** is set to `By semi-empirical formulas`.

### Laminar transition specification

If **Model parameterization** is set to `By semi-empirical formulas`, select how the block transitions between the laminar and turbulent regimes:

- `Pressure ratio` — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- `Reynolds number` — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 150. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

### Reynolds number vector

Specify the vector of input values for Reynolds numbers as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values are [-4000, -3000, -2000, -1000, -500, -200, -100, -50, -40, -30, -20, -15, -10, 10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000, 4000, 5000, 10000]. This parameter is used if **Model parameterization** is set to `By loss coefficient vs. Re table`.

### Loss coefficient vector

Specify the vector of the loss coefficient values as a one-dimensional array. The loss coefficient vector must be of the same size as the Reynolds numbers vector. The default values are [0.25, 0.3, 0.65, 0.9, 0.65, 0.75, 0.90, 1.15, 1.35, 1.65, 2.3, 2.8, 3.10, 5, 2.7, 1.8, 1.46, 1.3, 0.9, 0.65, 0.42, 0.3, 0.20, 0.40, 0.42, 0.25]. This parameter is used if **Model parameterization** is set to `By loss coefficient vs. Re table`.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- `Linear` — Select this option to get the best performance.
- `Smooth` — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page. This parameter is used if **Model parameterization** is set to `By loss coefficient vs. Re table`.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page. This parameter is used if **Model parameterization** is set to `By loss coefficient vs. Re table`.

## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Interpolation method**
- **Extrapolation method**
- **Laminar transition specification**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the resistance inlet.

B

Hydraulic conserving port associated with the resistance outlet.

## References

[1] Idelchik, I.E., *Handbook of Hydraulic Resistance*, CRC Begell House, 1994

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Elbow | Gradual Area Change | Pipe Bend | Sudden Area Change | T-junction

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Local Resistance (IL)

Pipe resistances in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



## Description

The Local Resistance (IL) block models pressure loss due to user-defined pipe resistances in an isothermal liquid system. You can specify different loss coefficients for forward and reversed flows through the pipe segment. For pipe bends, you can also choose to use the Isothermal Liquid library blocks Pipe Bend (IL) and Elbow (IL) or, for area changes, the Area Change (IL) block.

The loss factor is parameterized by either a constant relationship based on the pipe pressure or by user-supplied tabular data for loss coefficients based on the Reynolds number.

### Constant Loss Factor

Segments with loss factors that remain constant over a range of flow velocities are calculated as:

$$k_{loss} = k_{loss,BA} + \frac{(k_{loss,AB} - k_{loss,BA})}{2} \left[ \tanh\left(\frac{3\Delta p}{\Delta p_{crit}}\right) + 1 \right],$$

where:

- $k_{loss,AB}$  and  $k_{loss,BA}$  are the **Forward flow loss coefficient (from A to B)** and **Reverse flow loss coefficient (from B to A)** parameters, respectively.
- $\Delta p$  is the pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$  is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , which is the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\bar{\rho}}{2} k_{loss,crit} \left( \frac{\nu Re_{crit}}{D_h} \right)^2,$$

where:

- $k_{loss,crit}$  is the loss factor associated with the critical pressure, and is based on an average of the forward and reverse loss coefficients.
- $\nu$  is the fluid kinematic viscosity.
- $\bar{\rho}$  is the average fluid density.
- $D_h$  is the segment hydraulic diameter, which is the equivalent diameter of a pipe with a non-circular cross-section:  $D_h = \sqrt{\frac{4}{\pi A_{flow}}}$ , where  $A_{flow}$  is the **Flow area**.

### Tabulated Loss Coefficient

The loss coefficient can alternatively be interpolated from user-provided Reynolds number and loss coefficient data. The vector of Reynolds numbers can have both positive and negative values, indicating forward and reverse flow, respectively:  $k_{loss} = TLU(Re)$ .

### Mass Flow Rate

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = A_{flow} \frac{\sqrt{2\bar{\rho}}}{\sqrt{k_{loss}}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where  $k_{loss}$  is the flow loss coefficient, which is selected between the **Forward flow loss coefficient (from A to B)** and **Reverse flow loss coefficient (from B to A)** based on the block flow direction.

### Energy Balance

The block balances energy such that

$$\Phi_A + \Phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port to the pipe segment. Flow is positive from port **A** to port **B**.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port to the pipe segment. Flow is positive from port **A** to port **B**.

## Parameters

### Local loss parameterization – Loss factor calculation method

Constant (default) | Tabulated data - loss coefficient vs. Reynolds number

Method of calculating the pipe segment loss factor. The loss factor is parameterized by either a linear relationship between the segment pressure drop and constant loss factor or by interpolation of user-provided loss factor and Reynolds number data.

**Forward flow loss coefficient (from A to B) – Loss coefficient for flow from A to B**  
1 (default) | positive scalar

Loss coefficient associated with pressure loss for flows from port **A** to port **B**.

**Reverse flow loss coefficient (from B to A) – Loss coefficient for flow from B to A**  
1 (default) | positive scalar

Loss coefficient associated with pressure loss for flows from port **B** to port **A**.

**Reynolds number vector – Vector of Reynolds numbers for tabular parameterization**  
[-500, -200, -100, -50, -40, -30, -20, -10, 10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000] (default) | 1-by-*n* vector

Vector of Reynolds numbers for the tabular parameterization of the loss coefficient. The vector elements must correspond one-to-one with the elements in the **Loss coefficient vector** parameter. The elements are listed in ascending order.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Loss coefficient vector – Vector of loss coefficients for tabular parameterization**  
[.65, .75, .9, 1.15, 1.35, 1.65, 2.3, 3.1, 4, 2.7, 1.8, 1.46, 1.3, .9, .65, .42, .3, .2] (default) | 1-by-*n* vector

Vector of loss coefficients for the tabular parameterization of the loss coefficient. The vector elements must correspond one-to-one with the elements in the **Reynolds number vector** parameter. The elements must be greater than 0.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Flow area – Segment cross-sectional area**  
1e-3 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the pipe segment.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**  
150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

Area Change (IL) | Pipe Bend (IL) | Elbow (IL) | T-Junction (IL)



# Local Resistance (TL)

Pipe resistance in a thermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



## Description

The Local Resistance (TL) block represents pressure loss due to user-defined pipe resistance in a thermal liquid network. You can specify different loss coefficients for forward and reversed flows through the pipe segment. For pipe bends, you can also choose to use the Thermal Liquid library blocks Pipe Bend (TL) and Elbow (TL) or, for area changes, the Sudden Area Change (TL) block.

The loss factor is parameterized by either a constant relationship based on the pipe pressure or by user-supplied tabular data for loss coefficients based on the Reynolds number.

### Constant Loss Factor

Segments with loss factors that remain constant over a range of flow velocities are calculated as:

$$k_{loss} = k_{loss,BA} + \frac{(k_{loss,AB} - k_{loss,BA})}{2} \left[ \tanh\left(\frac{3\Delta p}{\Delta p_{crit}}\right) + 1 \right],$$

where:

- $k_{loss,AB}$  and  $k_{loss,BA}$  are the **Forward flow loss coefficient (from A to B)** and **Reverse flow loss coefficient (from B to A)** parameters, respectively.
- $\Delta p$  is the pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , which is the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\bar{\rho}}{2} k_{loss,crit} \left( \frac{\nu Re_{crit}}{D_h} \right)^2,$$

where:

- $k_{loss,crit}$  is the loss factor associated with the critical pressure, and is based on an average of the forward and reverse loss coefficients.
- $\nu$  is the fluid kinematic viscosity.
- $\bar{\rho}$  is the average fluid density.
- $D_h$  is the segment hydraulic diameter, which is the equivalent diameter of a pipe with a non-circular cross-section:  $D_h = \sqrt{\frac{4}{\pi A_{flow}}}$ , where  $A_{flow}$  is the **Flow area**.

### Tabulated Loss Coefficient

The loss coefficient can alternatively be interpolated from user-provided Reynolds number and loss coefficient data. The vector of Reynolds numbers can have both positive and negative values, indicating forward and reverse flow, respectively:  $k_{loss} = TLU(Re)$ .

### Mass Flow Rate

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = A_{flow} \frac{\sqrt{2\bar{\rho}}}{\sqrt{k_{loss}}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where  $k_{loss}$  is the flow loss coefficient, which is selected between the **Forward flow loss coefficient (from A to B)** and **Reverse flow loss coefficient (from B to A)** based on the block flow direction.

### Energy Balance

The block balances energy such that

$$\Phi_A + \Phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port associated with the entry or exit port to the pipe segment. Flow is positive from port **A** to port **B**.

#### B — Liquid port

isothermal liquid

Thermal liquid conserving port associated with the entry or exit port to the pipe segment. Flow is positive from port **A** to port **B**.

## Parameters

### Local loss parameterization — Loss factor calculation method

Constant (default) | Tabulated data - loss coefficient vs. Reynolds number

Method of calculating the pipe segment loss factor. The loss factor is parameterized by either a linear relationship between the segment pressure drop and constant loss factor or by interpolation of user-provided loss factor and Reynolds number data.

**Forward flow loss coefficient (from A to B) – Loss coefficient for flow from A to B**  
1 (default) | positive scalar

Loss coefficient associated with pressure loss for flows from port **A** to port **B**.

**Reverse flow loss coefficient (from B to A) – Loss coefficient for flow from B to A**  
1 (default) | positive scalar

Loss coefficient associated with pressure loss for flows from port **B** to port **A**.

**Reynolds number vector – Vector of Reynolds numbers for tabular parameterization**  
[-500, -200, -100, -50, -40, -30, -20, -10, 10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000] (default) | 1-by-*n* vector

Vector of Reynolds numbers for the tabular parameterization of the loss coefficient. The vector elements must correspond one-to-one with the elements in the **Loss coefficient vector** parameter. The elements are listed in ascending order.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Loss coefficient vector – Vector of loss coefficients for tabular parameterization**  
[.65, .75, .9, 1.15, 1.35, 1.65, 2.3, 3.1, 4, 2.7, 1.8, 1.46, 1.3, .9, .65, .42, .3, .2] (default) | 1-by-*n* vector

Vector of loss coefficients for the tabular parameterization of the loss coefficient. The vector elements must correspond one-to-one with the elements in the **Reynolds number vector** parameter. The elements must be greater than 0.

#### Dependencies

To enable this parameter, set **Local loss parameterization** to Tabulated data - loss coefficient vs. Reynolds number.

**Flow area – Segment cross-sectional area**  
1e-3 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the pipe segment.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**  
150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## Version History

Introduced in R2022a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

# Multiposition Valve Actuator

Multiposition actuator in any fluid domain

**Library:** Simscape / Fluids / Fluid Network Interfaces / Actuators

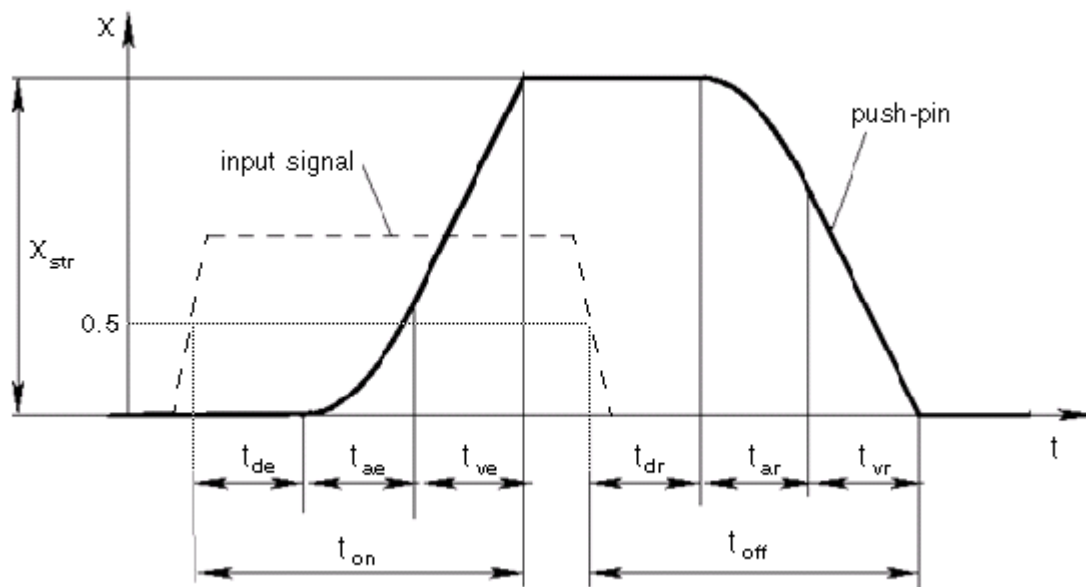


## Description

The Multiposition Valve Actuator block models a multiposition actuator in any fluid domain. You can use it in combination with any valve block that takes a physical signal as input. The actuator position is influenced by the input signal and switching time, and not by loading.

### Two-Position Actuator Movement

Actuation begins when the signal at port **A** exceeds 50% of the **Nominal signal value**. After the time period set by the **Switching-on time** parameter, the actuator begins to move toward the **Push-pin stroke limit**. When the input signal at port **A** falls below 50% of the **Nominal signal value**, the actuator reverses its direction after the time period set by the **Switching-off time** parameter. The motion can be interrupted mid-stroke.



### Actuator position

In the image above,  $t_{de}$  is the **Switching-on time**, which is equal to the time periods  $t_{ae}$  and  $t_{ve}$ . In region  $t_{ae}$ , the actuator moves at constant acceleration with parabolic displacement. In region  $t_{ve}$ , the actuator moves linearly, with constant velocity, toward full push-pin extension. The actuator switches direction when the control signal is off:

- 1  $t_{dr}$  is a transitional no-displacement time period set by the **Switching-off time**.

- 2  $t_{ar}$  is a period of acceleration with parabolic displacement.
- 3  $t_{vr}$  is period of linear displacement toward the actuator **Initial position**.

When **Actuator positions** is set to 2, the **Actuator travel direction** parameter sets the direction of the push-pin motion.

The actuator motion can be interrupted at any time. If the push-pin motion is disrupted mid-stroke, the switch-on and switch-off times are adjusted proportionally to the push-pin position, relative to the push-pin stroke.

### Three-Position Actuator Movement

When **Actuator positions** is set to 3, the signal at port **A** moves the actuator in a positive direction and the signal received at port **B** moves the actuator in a negative direction. Only one signal, from one port, is processed at a time. To switch control between ports **A** and **B**, or between positive and negative displacement control, the actuator must first move to a neutral position. If the push-pin motion is disrupted mid-stroke, the switch-on and switch-off times are adjusted proportionally to the push-pin position, relative to the push-pin stroke. The actuator motion can be interrupted at any time.

When controlled by the signal at port **A**, the three-position actuator has the same displacement profile as the two-position actuator when **Actuator travel direction** is set to **Positive**. When controlled by the signal at port **B**, it has the same profile as the two-position actuator when **Actuator travel direction** is set to **Negative**.

## Ports

### Input

#### **A – Input signal**

physical signal

Input port, specified as a physical signal.

When **Actuator positions** is set to 2, this port can either control negative or positive actuator movement, according to the **Actuator orientation** setting.

When **Actuator positions** is set to 3, this port receives a physical signal that corresponds to a positive actuator displacement direction.

#### **B – Input signal**

physical signal

Input port for negative actuator displacement, received as a physical signal.

### Dependencies

To enable this port, set **Actuator positions** to 3.

### Output

#### **S – Actuator position, m**

physical signal

Actuator position, in m, specified as a physical signal.

If you use the Multiposition Valve Actuator block with a valve from the Gas Library, the gas block converts the actuator signal units of m to units of 1.

## Parameters

### Actuator positions — Number of valve position signals

2 (default) | 3

Number of valve position signals. When set to 2, the actuator receives one signal and sets one position signal. When set to 3, the actuator receives a positive and a negative signal and sets one position signal.

### Push-pin stroke — Maximum push-pin extension

0.01 m (default) | positive scalar

Maximum push-pin extension.

### Switching-on time — Signal transition time period

0.1 s (default) | positive scalar

Transitional time period before the actuator begins to move. The period begins after the input signal rises above 50% of the **Nominal signal value**.

### Switching-off time — Signal transition time period

0.1 s (default) | positive scalar

Transitional time period before the actuator reverses motion. The period begins after the input signal falls below 50% of the **Nominal signal value**.

### Nominal signal value — Nominal signal for fully extended actuator

24 (default) | positive scalar

Nominal signal for fully extended actuator. The actuator motion is triggered when the input signal reaches 50% of the **Nominal signal value**.

### Initial position — Actuator starting position

Retracted (default) | Extended | Neutral

Starting position of the actuator. Retracted and Extended correspond to the actuator push-pin stroke limits.

When **Actuator positions** is set to 2, the **Initial position** default is Retracted. When **Actuator positions** is set to 3, the **Initial position** default is Neutral. Neutral corresponds to the middle of the **Push-pin stroke**.

### Actuator orientation — Direction of actuator motion

Positive (default) | Negative

Direction of the actuator motion in response to the physical signal input. The Positive setting corresponds to push-pin extension.

### Dependencies

To enable this parameter, set **Actuator positions** to 2.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

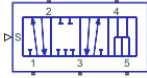
Proportional Valve Actuator | Pilot Valve Actuator (IL) | Cartridge Valve Actuator (IL) | 2-Way Directional Valve (IL) | 3-Way Directional Valve (IL) | 4-Way 3-Position Directional Valve (IL)



## M-Way N-Position Directional Valve (IL)

M-way, N-position valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves

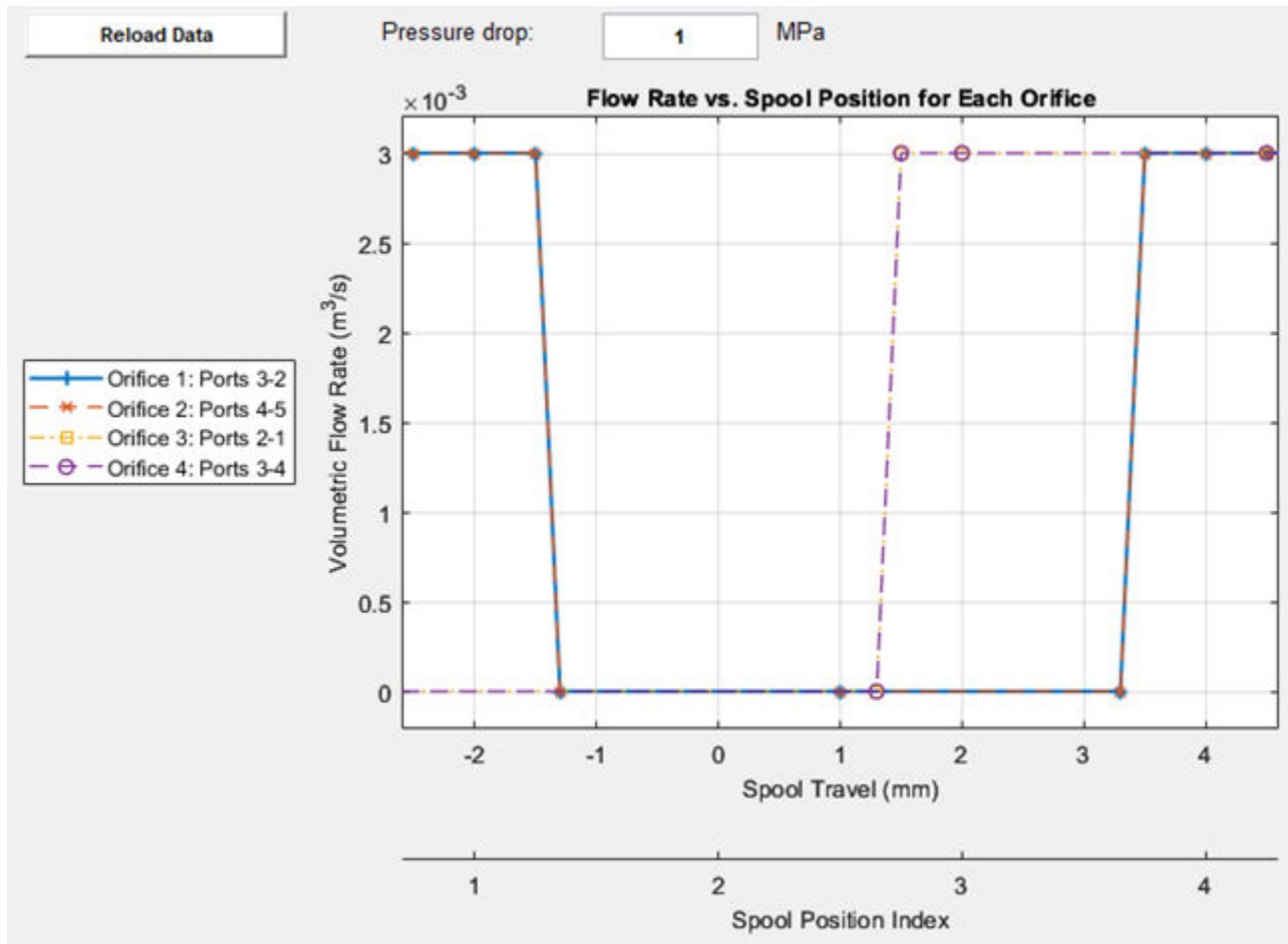


### Description

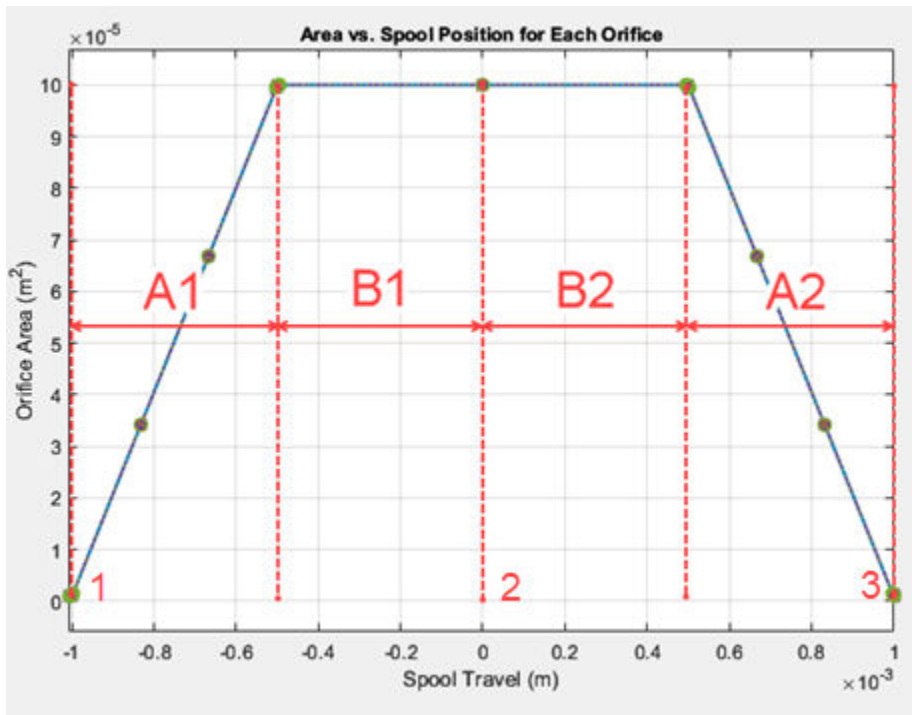
The M-Way N-Position Directional Valve (IL) block represents a spool-operated directional valve with an arbitrary configuration of ports, spool positions, and orifices. The block accepts up to ten ports, ten spool positions, and 20 orifices. Valves with many configurations are most common in construction, agriculture, and some vehicle applications. This block simplifies complex parameterizations by allowing you to apply the same area characteristics to all flow paths. You can also individually specify the area characteristics for each flow path. You can parameterize the valve by specifying the opening area or by using tabulated data that represents volumetric flow rate for a fully open orifice at varied pressure drops. The block uses a variable orifice to control the flow between a given pair of connected ports. The physical signal at port **S** triggers the spool motion to open or shut the valve. For more details about how the block calculates flow rate through a variable orifice, see Orifice (IL).

You can generate a characteristic plot of the valve by right-clicking the block and selecting **Fluids > Plot Valve Characteristics**. To update the plot after changing the block parameters, click the **Reload Data** button. You can control the shape of the characteristic plot. To select which lines are visible, click the appropriate orifice on the legend.

The default valve characteristic plot is:



The figure indicates locations A1, A2, B1, and B2.



Position 1 is at spool travel of -1 mm. Position 2 is at spool travel of 0 mm, and Position 3 is at spool travel of 1 mm. Locations A1 and A2 represent the left- and right-side transition regions of the orifice opening area, respectively. Locations B1 and B2 represent the left- and right-side fully open regions of the orifice opening area, respectively. The current spool position is the separation between B1 and B2. When you set **Area characteristics** to Identical for all flow paths.

- $A1 = (\text{distance between spool positions 1 and 2}) * (\text{value of the } \mathbf{Inter\text{-}position\ spool\ travel\ fraction\ for\ which\ orifices\ transition\ between\ open\text{-}closed}$  parameter)
- $A2 = (\text{distance between spool positions 2 and 3}) * (\text{value of the } \mathbf{Inter\text{-}position\ spool\ travel\ fraction\ for\ which\ orifices\ transition\ between\ open\text{-}closed}$  parameter)
- $B1 = (\text{distance between spool positions 1 and 2}) * (\text{value of the } \mathbf{Inter\text{-}position\ spool\ travel\ fraction\ for\ which\ orifices\ remain\ fully\ open}$  parameter)
- $B2 = (\text{distance between spool positions 2 and 3}) * (\text{value of the } \mathbf{Inter\text{-}position\ spool\ travel\ fraction\ for\ which\ orifices\ remain\ fully\ open}$  parameter)

When you set **Area characteristics** to Different for each flow path:

- $A1 = A2 = \text{value of the } \mathbf{Spool\ travel\ for\ which\ orifice\ 2\ transitions\ between\ open\text{-}closed}$  parameter.
- $B1 = B2 = \text{value of the } \mathbf{Spool\ travel\ for\ which\ orifice\ 2\ remains\ fully\ open}$  parameter.

### Orifice Parameterization

When you set **Area parameterization** to Different for each flow path, you can parameterize each orifice by using the parameters in the **Orifice 1,...,20** sections. For example, if you set **Number of orifices** to 3, the block includes sections for **Orifice 1**, **Orifice 2**, and **Orifice 3**. Each section has the same parameter names followed by the number for that section.

The block icon updates automatically to indicate the orifice configuration, which you control with the appropriate **Ports connected by orifice...** parameter. If you connect one odd-numbered port to one even-numbered port, the block icon shows an arrow that points to the second listed port. The block icon indicates when a parameterization is invalid.

### Assumptions and Limitations

- The block supports only linearly varying opening areas.
- The block assumes that each orifice has a symmetric opening and closing about the spool position when you set **Area characteristics** to **Different** for each flow path.
- The block assumes that each orifice has a symmetric opening and closing scaled with the spacing of the **Spool travel at each spool position index** parameter when you set **Area characteristics** to **Identical** for each flow path.

## Ports

### Input

#### **S — Spool displacement, m**

physical signal

Physical signal input port associated with the spool displacement, in m.

### Conserving

#### **1 — Port 1**

isothermal liquid

Isothermal liquid conserving port associated with port 1.

#### **2, . . . , 10 — Ports with parameter dependencies**

isothermal liquid

Isothermal liquid conserving ports associated with port 2 through 10, where the number of ports is equal to the **Number of ports** parameter.

### Dependencies

To enable ports 2 through 10, set **Number of ports** to the number of ports you want.

## Parameters

### Valve Configuration

#### **Number of ports — Number of valve ports**

2 (default) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10

Number of ports associated with the valve, *M*. You can select up to ten.

#### **Number of spool positions — Number of spool positions**

2 (default) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10

Number of spool positions, *N*. You can select up to ten.

**Number of orifices — Number of orifices**

1 (default) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20

Number of orifices. You can select up to 20.

**Spool travel at each spool position index — Spool travel**[-2, 0, 2, 4] mm (default) | vector of length  $N$ 

Spool travel values. Each element corresponds to a different spool position index. The length of this vector must be equal to length of the **Number of spool positions** parameter,  $N$ . A value of 0 represents a neutral spool position.

**Area characteristics — Area characteristic parameterization option**

Identical for all flow paths (default) | Different for each flow path

Whether to apply identical or different parameterizations for each orifice.

**Inter-position spool travel fraction for which orifices remain fully open — Fully open flow between spool positions**

0.5 (default) | scalar in the range [0,1)

Fractional distance between adjacent spool positions for which each orifice remains at the maximum opening area.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for each flow path.

**Inter-position spool travel fraction for which orifices transition between open-closed — Spool travel from open to closed**

0.1 (default) | nonnegative scalar

Fractional distance between adjacent spool positions over which the orifice area transitions between maximum area and leakage area.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for each flow path.

**Orifice parameterization — Orifice parameterization**

Orifice area (default) | Tabulated data - Volumetric flow rate vs. pressure drop

Whether to parameterize each orifice by area or by using tabulated volumetric flow rate data according to pressure drop.

**Maximum orifice area — Maximum orifice area**1e-4 m<sup>2</sup> (default) | positive scalar

Maximum opening area for all orifices.

**Dependencies**

To enable this parameter, set **Area characteristics** to Identical for each flow path and **Orifice parameterization** to Orifice area.

**Leakage area fraction — Leakage area fraction**

0.01 (default) | positive scalar

Leakage area as a fraction of the value of the **Maximum orifice area** parameter.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Cross-sectional area at ports – Cross-sectional area for all ports**

`inf m2 (default) | positive scalar`

Cross-sectional area for all ports.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Discharge coefficient – Discharge coefficient**

`0.64 (default) | positive scalar`

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Critical Reynolds number – Critical Reynolds number**

`150 (default) | positive scalar`

Upper Reynolds number limit for laminar flow through the orifice.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Smoothing factor – Numerical smoothing factor**

`0.01 (default) | positive scalar`

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to improve the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Pressure recovery – Option to account for pressure increases in area expansions**

`Off (default) | On`

Whether to account for pressure increase when fluid flows from a region of smaller restriction area to a region of larger cross-sectional area.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Orifice area`.

**Pressure drop vector – Tabulated pressure drop**

`[-.1, .3, .5, .7] MPa (default) | vector of length X`

Tabulated pressure drop values for all orifices. The elements of this vector correspond one-to-one with the **Fully open volumetric flow rate vector** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for each flow path and **Orifice parameterization** to `Tabulated data - Volumetric flow rate vs. pressure drop`.

**Fully open volumetric flow rate vector – Tabulated volumetric flow rate**

`[-.0009, .0016, .002, .0024] m3/s (default) | vector of length X`

Volumetric flow rate for a fully open orifice at a given pressure drop. The elements of this vector correspond one-to-one with the **Pressure drop vector** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to `Identical` for each flow path and **Orifice parameterization** to `Tabulated data - Volumetric flow rate vs. pressure drop`.

**Leakage flow rate fraction – Leakage flow rate fraction**

`0.01 (default) | positive scalar`

Leakage as a fraction of the **Fully open volumetric flow rate vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to `Tabulated data - Volumetric flow rate vs. pressure drop`.

**Orifice 1**

This section includes only the parameters for orifice 1. The remaining orifice parameters are identical to orifice 1 except for their number and the cases mentioned in the parameter descriptions for orifice 1. To learn more, see “Orifice Parameterization” on page 1-1213.

**Ports connected by orifice 1 – Ports connected by orifice 1**

`[3, 2] (default) | vector of length 2`

The two fluid ports connected by orifice 1. The first element is the valve port connected to the orifice A port. The second element is the valve port connected to the orifice B port. In the **Simscape Results Explorer** app, the variables `mdot_A` and `mdot_B` are mass flow rates into the Orifice (IL) block A and B ports, respectively. `p_diff` is the pressure drop from port A to port B of the orifice. In the block icon, for ports connected to a single orifice, the arrow points to the port represented by the second element of this parameter. The default values for the other orifices are:

- Orifice 2: [4, 5]
- Orifice 3: [2, 1]
- Orifice 4: [3, 4]
- Orifice 5-Orifice 20: [1, 2]

**Spool position indices where orifice 1 is open – Orifice 1 open positions**

`[1, 4] (default) | vector of length 1 to N`

Spool positions for which orifice 1 is open. The vector must be strictly monotonically increasing with values between 1 and the value of the **Number of spool positions** parameter. The default values for the other orifices are:

- Orifice 2: [1, 4]
- Orifice 3: [3, 4]
- Orifice 4: [3, 4]
- Orifice 5-Orifice 20: 1

**Spool travel for which orifice 1 remains fully open – Fully open spool travel**

1 mm (default) | nonnegative scalar

Spool travel across which the orifice maintains the maximum opening area. The center of this spool travel distance is at the value of the **Spool position with open orifice 1** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path.

**Spool travel for which orifice 1 transitions between open-closed – Threshold spool travel**

0.2 mm (default) | positive scalar

Spool travel across which the orifice transitions from fully open to fully closed.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path.

**Maximum area of orifice 1 – Orifice area when fully open**1e-4 m<sup>2</sup> (default) | positive scalar

Opening area of orifice 1.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path.

**Pressure drop vector of orifice 1 – Orifice 1 pressure drop**

[-.1, .3, .5, .7] MPa (default) | vector of length X

Vector of pressure drop values for orifice 1. These values correspond one-to-one with the **Fully open volumetric flow rate vector of orifice 1** parameter.

**Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. pressure drop.

**Fully open volumetric flow rate vector of orifice 1 – Orifice 1 fully open volumetric flow rate**[-.0009, .0016, .002, .0024] m<sup>3</sup>/s (default) | vector of length X

Volumetric flow rate when orifice 1 is fully open for a given pressure drop. These values correspond one-to-one with the **Pressure drop vector of orifice 1** parameter.



### **Dependencies**

To enable this parameter, set **Area characteristics** to Different for each flow path and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. pressure drop.

## **Version History**

**Introduced in R2022b**

### **See Also**

4-Way 3-Position Directional Valve (IL)

# Needle Valve

Hydraulic needle valve

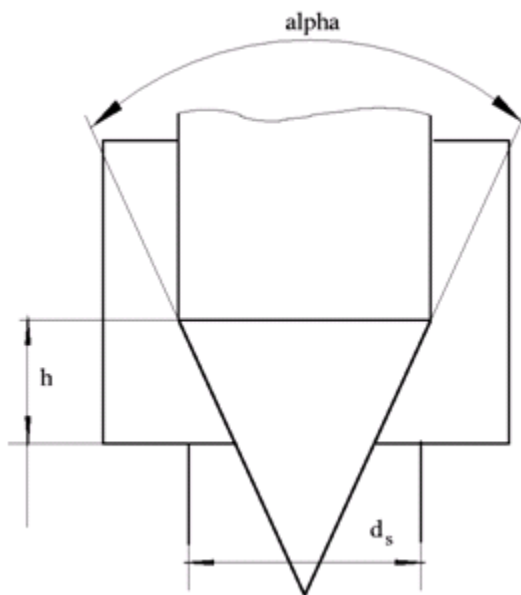


## Library

Flow Control Valves

## Description

The Needle Valve block models a variable orifice created by a conical needle and a round sharp-edged orifice in thin material.



The flow rate through the valve is proportional to the valve opening and to the pressure differential across the valve. The flow rate is determined according to the following equations:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

$$\Delta p = p_A - p_B,$$

$$h = x_0 + x$$

$$h_{\max} = d_s \frac{1 - \sqrt{1 - \cos \frac{\alpha}{2}}}{\sin \alpha}$$

$$A(h) = \begin{cases} A_{\text{leak}} & \text{for } h < = 0 \\ \pi \cdot \left( d_s - h \cdot \sin \frac{\alpha}{2} \cdot \cos \frac{\alpha}{2} \right) \cdot h \cdot \sin \frac{\alpha}{2} + A_{\text{leak}} & \text{for } 0 < h < h_{\max} \\ A_{\max} + A_{\text{leak}} & \text{for } h > = h_{\max} \end{cases}$$

$$A_{\max} = \frac{\pi d_s^2}{4}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A(h)$	Instantaneous orifice passage area
$x_0$	Initial opening
$x$	Needle displacement from initial position
$h$	Valve opening
$h_{\max}$	Maximum needle stroke
$d_s$	Orifice diameter
$\alpha$	Needle angle
$\rho$	Fluid density
$A_{\text{leak}}$	Closed valve leakage area
$A_{\max}$	Maximum valve open area
$p_{\text{cr}}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{\text{cr}}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = (p_{\text{avg}} + p_{\text{atm}})(1 - B_{\text{lam}})$$

$$p_{\text{avg}} = (p_A + p_B)/2$$

where

$p_{\text{avg}}$	Average pressure between the block terminals
$p_{\text{atm}}$	Atmospheric pressure, 101325 Pa
$B_{\text{lam}}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Valve instantaneous hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S opens the valve.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- The flow passage area is assumed to be equal to the frustum side surface area.

## Parameters

### Valve orifice diameter

The diameter of the orifice of the valve. The default value is 0.005 m.

### Needle cone angle

The angle of the valve conical needle. The parameter value must be in the range between 0 and 180 degrees. The default value is 90 degrees.

### Initial opening

The initial opening of the valve. You can specify both positive and negative values. The default value is 0.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.65.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to Pressure ratio.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 10. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

S

Physical signal port to control spool displacement.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Ball Valve | Gate Valve | Poppet Valve | Pressure-Compensated Flow Control Valve

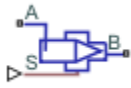
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Needle Valve (IL)

Needle valve in an isothermal liquid system

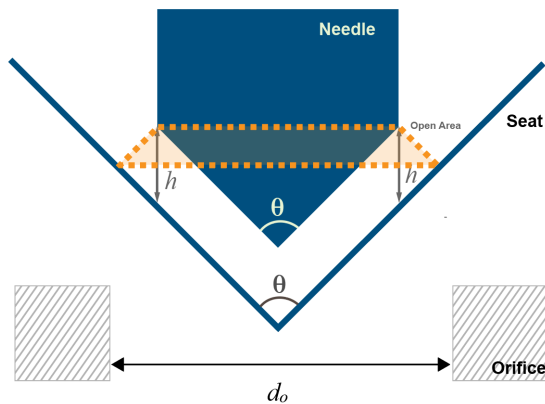
**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



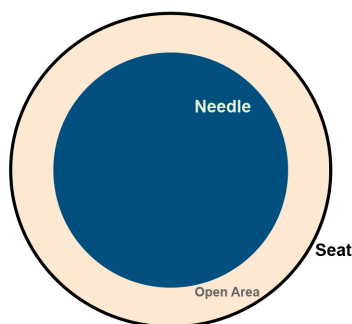
## Description

The Needle Valve (IL) block models flow reductions by a needle valve. The valve comprises a conical needle and a round, sharp-edged seat. The needle opens or closes according to the displacement signal at port S. A positive signal retracts the needle and opens the valve.

### Opening Area



### Needle Valve Schematic



### Needle Valve Top View

The opening area of the valve is calculated as:

$$A_{open} = \pi h \sin\left(\frac{\theta}{2}\right) \left[ d_o - \frac{h}{2} \sin(\theta) \right] + A_{leak}$$

where:

- $h$  is the vertical distance between the outer edge of the needle and the seat, as indicated in the schematic above.
- $\theta$  is the seat cone angle, which always matches the **Needle cone angle**.
- $d_0$  is the **Seat orifice diameter**.
- $A_{leak}$  is the **Leakage area**.

The opening area is bounded by the maximum displacement  $h_{max}$ :

$$h_{max} = \frac{d_0 \left[ 1 - \sqrt{1 - \cos\left(\frac{\theta}{2}\right)} \right]}{\sin(\theta)}.$$

For any needle displacement larger than  $h_{max}$ ,  $A_{open}$  is the sum of the maximum orifice area and the **Leakage area**:

$$A_{open} = \frac{\pi}{4} d_0^2 + A_{leak}.$$

For any combination of the signal at port **S** and the needle offset that is less than 0, the minimum valve area is the **Leakage area**.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the displacement between  $\theta$  and  $h_{max}$ . For more information, see “Numerical Smoothing”.

### Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left( 1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 \right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{valve}$  is the instantaneous valve open area.
- $A_{port}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$



*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port to the valve.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port to the valve.

### Input

#### S – Needle displacement, m

physical signal

Control member displacement in m, specified as a physical signal. A positive signal retracts the needle and opens the valve.

## Parameters

#### Seat orifice diameter – Diameter of seat

5e-3 m (default) | positive scalar

Diameter of the seat orifice.

#### Needle cone angle – Control member geometry angle

90 deg (default) | positive scalar

Control member geometry angle. Refer to the “Needle Valve Schematic” on page 1-1225 in the valve description.

#### Needle position when in the seat – Needle offset

0 m (default) | scalar

Needle offset when the valve is closed. A positive, nonzero value indicates a partially open valve. A negative, nonzero value indicates an overlapped valve that remains closed for an initial displacement set by the physical signal at port S.

**Leakage area — Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Cross-sectional area at ports A and B — Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

## Version History

Introduced in R2020a

### Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Poppet Valve (IL) | Gate Valve (IL) | Shuttle Valve (IL)

## Orifice (IL)

Constant-area or variable-area orifice in an isothermal system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Orifices

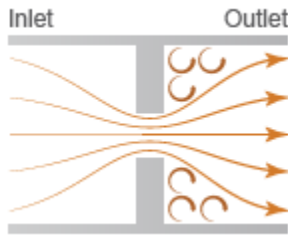


### Description

The Orifice (IL) block models the flow through a local restriction with a constant or variable opening area. For variable orifices, a control member connected to port **S** sets the opening position. The opening area is parametrized either linearly or by lookup table.

For orifices that open and close based on the displacement of a central spool, see Spool Orifice (IL).

You can enable fault modeling behavior by setting **Enable faults** to On.



The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = \rho v_A A_A + \rho v_B A_B = 0.$$

This mass balance implies that there is an increase in velocity when there is a decrease in area, and a reduction in velocity when the flow discharges into a larger area. In accordance with the Bernoulli principle, this change in velocity results in a region of lower pressure in the orifice and a higher pressure in the expansion zone. The resulting increase in pressure, which is called *pressure recovery*, depends on the discharge coefficient of the orifice and the ratio of the orifice and port areas.

### Constant Orifices

For constant orifices, the orifice area,  $A_{\text{orifice}}$ , does not change over the course of the simulation.

#### Using the Constant Area Parameterization

The block calculates the mass flow rate as

$$\dot{m} = \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2\right)}} \sqrt{p_A - p_B} \approx \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2\right)}} \frac{p_A - p_B}{\left[(p_A - p_B)^2 + \Delta p_{\text{crit}}\right]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{\text{orifice}}$  is the instantaneous orifice open area.
- $A_{\text{port}}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.

$PR_{\text{loss}}$  and  $\Delta p_{\text{crit}}$  are calculated in the same manner for constant and variable orifices and are defined in the “Pressure Loss” on page 1-1231 and “Critical Pressure” on page 1-1232 sections below.

This approximation for  $\dot{m}$  and the Local Restriction (IL) block are the same.

#### Using the Tabulated data - Volumetric flow rate vs. pressure drop Parameterization

The volumetric flow rate is determined from the tabular values of the pressure differential,  $\Delta p$ , which you can provide. If only non-negative values are provided for both the volumetric flow rate and pressure drop vectors, the table will be extrapolated to contain negative values. The volumetric flow rate is interpolated from this extended table.

#### Variable Orifices

For variable orifices, setting **Opening orientation** to `Positive` control member displacement opens orifice opens the orifice when the signal at **S** is positive, while a `Negative` control member displacement opens orifice orientation opens the orifice when the signal at **S** is negative. In both cases, the signal is positive and the orifice opening is set by the magnitude of the signal.

#### Using the Linear - Area vs. control member position Parameterization

The orifice area  $A_{\text{orifice}}$  is based on the control member position and the ratio of orifice area and maximum control member position:

$$A_{\text{orifice}} = \frac{(A_{\text{max}} - A_{\text{leak}})}{\Delta S}(S - S_{\text{min}})\varepsilon + A_{\text{leak}}$$

where:

- $S_{\text{min}}$  is the control member position when the orifice is fully closed.
- $\Delta S$  is the **Control member travel between closed and open orifice**.
- $A_{\text{max}}$  is the **Maximum orifice area**.
- $A_{\text{leak}}$  is the **Leakage area**.
- $\varepsilon$  is the **Opening orientation**.

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the orifice area between  $A_{\text{leak}}$  and  $A_{\text{max}}$ . For more information, see “Numerical Smoothing”.

The volumetric flow rate is determined by the pressure-flow rate equation:

$$\dot{m} = \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left( 1 - \left( \frac{A_{\text{orifice}}}{A} \right)^2 \right) [\Delta p^2 + \Delta p_{\text{crit}}^2]^{1/4}}} \Delta p$$

where  $A$  is the **Cross-sectional area at ports A and B**.

### Using the Tabulated data - Area vs. control member position Parameterization

When you use the Tabulated data - Area vs. control member position parameterization, the orifice area  $A_{\text{orifice}}$  is interpolated from the tabular values of opening area and the control member position,  $\Delta S$ , which you can provide. As with the Linear - Area vs. control member position parameterization, the volumetric flow rate is determined by the pressure-flow rate equation:

$$\dot{m} = \frac{C_d A_{\text{orifice}} \sqrt{2\bar{p}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A}\right)^2\right) [\Delta p^2 + \Delta p_{\text{crit}}^2]^{1/4}} \Delta p$$

where  $A_{\text{orifice}}$  is:

- $A_{\text{max}}$ , the last element of the **Orifice area vector**, if the opening is larger than the maximum specified opening.
- $A_{\text{leak}}$ , the first element of the **Orifice area vector**, if the orifice opening is less than the minimum opening.
- $A_{\text{orifice}}$  if the calculated area is between the limits of the **Orifice area vector**.

$A_{\text{open}}$  is a function of the control member position received at port **S**. The block queries between data points with linear interpolation and uses nearest extrapolation for points beyond the table boundaries.

### Using the Tabulated data - Volumetric flow rate vs. control member position and pressure drop Parameterization

The Tabulated data - Volumetric flow rate vs. control member position and pressure drop parameterization interpolates the volumetric flow rate directly from a user-provided volumetric flow rate table, which is based on the control member position and pressure drop over the orifice. The block queries between data points with linear interpolation and uses linear extrapolation for points beyond the table boundaries.

This data can include negative pressure drops and negative opening values. If a negative pressure drop is included in the dataset, the volumetric flow rate will change direction. However, the flow rate will remain unchanged for negative opening values.

### Pressure Loss

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area. The pressure loss term,  $PR_{\text{loss}}$  is calculated as:

$$PR_{\text{loss}} = \frac{\sqrt{1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{\text{orifice}}}{A_{\text{port}}}}{\sqrt{1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{\text{orifice}}}{A_{\text{port}}}}$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{\text{loss}}$  is 1.

## Critical Pressure

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , which is the point of transition between laminar and turbulent flow in the fluid:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{orifice}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

## Faults

When **Orifice type** is set to Variable and faults are enabled, the orifice open area becomes stuck at a specified value in response to one or both of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port T.

Three fault options are available in the **Opening area when faulted** parameter:

- Closed — The orifice freezes at its smallest value, depending on the **Orifice parameterization**:
  - When **Orifice parameterization** is set to Linear - Area vs. control member position, the orifice freezes at the **Leakage area**.
  - When **Orifice parameterization** is set to Tabulated data - Area vs. control member position, the orifice freezes at the first element of the **Orifice area vector**.
  - When **Orifice parameterization** is set to Tabulated data - Volumetric flow rate vs. control member position and pressure drop, the orifice freezes at the first row of the **Volumetric flow rate table, q(s,dp)**.
- Open — The orifice freezes at its largest value, depending on the **Orifice parameterization**:
  - When **Orifice parameterization** is set to Linear - Area vs. control member position, the orifice freezes at the **Maximum orifice area**.
  - When **Orifice parameterization** is set to Tabulated data - Area vs. control member position, the orifice freezes at the last element of the **Orifice area vector**.
  - When **Orifice parameterization** is set to Tabulated data - Volumetric flow rate vs. control member position and pressure drop, the orifice freezes at the last row of the **Volumetric flow rate table, q(s,dp)**.
- Maintain at last value — The orifice seizes at the open area or volumetric flow rate when the trigger occurs.

Due to numerical smoothing at the extremes of the orifice area, the minimum area applied is larger than the parameter value, and the maximum is smaller than the parameter value, in proportion to the **Smoothing factor** value.

Once triggered, the orifice remains at the faulted area for the rest of the simulation.

You can set the block to issue a fault report as a warning or error message in the Simulink Diagnostic Viewer with the **Reporting when fault occurs** parameter.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit point to the orifice.

#### B – Liquid port

isothermal liquid

Liquid entry or exit point to the orifice.

### Input

#### S – Control member displacement

physical signal

Control member displacement that sets orifice opening.

#### T – External fault trigger

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

### Dependencies

This port is visible when **Enable faults** is set to On and **Enable external fault trigger** is set to On.

## Parameters

### Parameters

#### Orifice type – Type of orifice

Variable (default) | Constant

Type of orifice, defined by the orifice area. When set to *Variable*, the orifice area varies according to the input signal received at port **S**.

#### Orifice parameterization – Method of calculating orifice area

Orifice Area (default) | Tabulated data - volumetric flow rate vs. pressure drop | Linear - area vs. control member position | Tabulated data - Area vs. control member position | Tabulated data - Volumetric flow rate vs. control member position and pressure drop

Method of calculating orifice area over simulation. When **Orifice type** is set to *Constant*, there are two parameterization options.

- **Orifice area** (default). The assigned area does not change over the simulation.
- **Tabulated data - Volumetric flow rate vs. pressure drop**. The area remains constant, but the volumetric flow rate through the orifice can vary. This value is interpolated directly from the **Volumetric flow rate vector** and the **Pressure drop vector** dataset.

When the **Orifice type** is set to **Variable**, there are three parameterization options.

- **Linear** - Area vs. control member position. Area is determined by a linear relationship to the control member position with respect to a fully open or fully closed orifice. The position is set by a varying physical signal at port **S**.
- **Tabulated data** - Area vs. control member position. The opening area is interpolated from the **Control member position vector** and the **Orifice area vector** based on the control member position received at port **S**.
- **Tabulated data** - Volumetric flow rate vs. control member position and pressure drop. The volumetric flow rate is directly interpolated from the user- provided **Control member position vector, s, Pressure drop vector, dp, and Volumetric flow rate table, q(s,dp)** parameters based on the control member position received at port **S** and the pressure drop across ports **A** and **B**.

#### **Orifice area — Area of orifice opening**

$1e-3 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening.

#### **Dependencies**

To enable this parameter, set **Orifice type** to **Constant** and **Orifice parameterization** to **Orifice area**.

#### **Pressure drop vector — Vector of differential pressure values for tabular parameterization**

$[-4, -3, -2, -1, -.5, 0, .5, 1, 2, 3, 4]$  MPa (default) | 1-by-*n* vector

Vector of pressure differential values for the tabular parameterization of volumetric flow rate. The values in this vector correspond one-to-one to values in the **Volumetric flow rate vector** parameter. The pressure drop vector values are listed in ascending order. The volumetric flow rate is interpolated directly from the **Volumetric flow rate vector**, which depends on the **Pressure drop vector** parameter.

#### **Dependencies**

To enable this parameter, set **Orifice type** to **Constant** and **Orifice parameterization** to **Tabulated data - Volumetric flow rate vs. pressure drop**.

#### **Volumetric flow rate vector — Vector of volumetric flow rate values**

$[-2.44, -2.12, -1.68, -1.22, -.84, 0, .85, 1.21, 1.7, 2.09, 2.41]$   $\cdot 1e-3 \text{ m}^3/\text{s}$  (default) | 1-by-*n* vector

Vector of volumetric flow rate values for the tabular parameterization of volumetric flow rate. The values in this vector correspond one-to-one to values in the **Pressure drop vector**. The volumetric flow rate is interpolated directly from the provided **Volumetric flow rate vector**, which depends on the **Pressure drop vector** parameter.

#### **Dependencies**

To enable this parameter, set **Orifice type** to **Constant** and **Orifice parameterization** to **Tabulated data - Volumetric flow rate vs. pressure drop**.

#### **Control member position at closed orifice — Control member offset**

$0 \text{ m}$  (default) | scalar



Initial control member offset when the variable orifice is fully closed.

#### Dependencies

To enable this parameter, set **Orifice type** to Variable.

#### Control member travel between closed and open orifice – Control member maximum stroke

5e-3 m (default) | positive scalar

Maximum distance the control member travels between closed and open orifice. The orifice is fully open at the sum of the **Control member position at closed orifice** and **Control member travel between closed and open orifice**,

#### Dependencies

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

#### Maximum orifice area – Maximum orifice opening area

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum orifice area experienced during simulation. When using Tabulated data - Area vs. control member position, the maximum orifice area is the last element of the **Orifice area vector**.

#### Dependencies

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

#### Leakage area – Orifice gap area when in fully closed position

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in fully closed position. Any area smaller than this value is maintained at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

#### Dependencies

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

#### Control member position vector – Vector of control member positions

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member positions for the tabular parameterization of orifice area. The vector elements correspond one-to-one to the values in the **Orifice area vector**. The vector elements are listed in ascending order and the first element must be 0. The orifice opening area is interpolated from the **Orifice area vector**, which depends on the **Control member position vector** parameter.

#### Dependencies

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Orifice area vector – Vector of orifice opening area values**

[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of orifice area values for the tabular parameterization of orifice area. The values in this vector correspond one-to-one with the elements in the **Control member position vector**. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area. The orifice opening area is interpolated from the **Orifice area vector**, which depends on the **Control member position vector**.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Cross-sectional area at ports A and B – Area at orifice entry or exit**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. This area is used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Opening orientation – Direction of member movement that opens the orifice**

Positive control member displacement opens orifice (default) | Negative control member displacement opens orifice

Direction of member displacement that opens a variable orifice. A positive orientation means that a positive signal at **S** opens the orifice. A negative orientation means that a negative signal at **S** opens the orifice.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Pressure recovery — Whether to account for pressure increase in area expansions**

On (default) | Off

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area. This increase in pressure is not captured when **Pressure recovery** is set on Off.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Control member position vector,  $s$  — Vector of opening values**

[0, .002, .004, .007, .017] m (default) | 1-by- $n$  vector

Vector of control member positions for tabular parametrization of volumetric flow rate. The control member position vector forms an independent axis with the **Pressure drop vector,  $dp$**  parameter for the 2-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop.

**Pressure drop vector,  $dp$  — Vector of pressure drop values**

[.3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Control member position vector,  $s$**  parameter for the 2-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop.

**Volumetric flow rate table,  $q(s, dp)$  — Array of volumetric flow rate values**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and control member position.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Control member position vector,  $s$**  parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop.

**Faults****Enable faults — Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Opening area when faulted — Set faulted area**

Closed (default) | Open | Maintain at last value

Sets the faulted orifice area. You can choose for the orifice to seize at the fully closed or fully open position, or at the valve area when faulting is triggered.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Enable faults** to On.

**Enable external fault trigger — External trigger option**

Off (default) | On

Enables port **T**. A physical signal at port **T** that is greater than 0.5 triggers faulting.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Enable faults** to On.

**Enable temporal fault trigger — Temporal trigger option**

Off (default) | On

Enables fault triggering at a specified time. When the **Simulation time for fault event** is reached, the orifice area will be set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Enable faults** to On.

**Simulation time for fault event — Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the orifice area is set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Enable faults** to On, and **Enable temporal fault trigger** to On.

**Reporting when fault occurs — Fault condition report**

None (default) | Warning | Error

Reporting preference for the fault condition. When reporting is set to Warning or Error, a message is displayed in the Simulink Diagnostic Viewer. When Error is selected, the simulation will stop if faulting occurs.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Enable faults** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Spool Orifice (IL) | Variable Overlapping Orifice (IL) | Annular Leakage (IL) | Local Restriction (IL)

## Orifice (G)

Flow restriction in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices



### Description

The Orifice (G) block represents the pressure loss incurred in a gas network due to a purely resistive element of fixed or variable size, such as a flow restriction, orifice, or valve. You can use orifices to measure and report gas flow characteristics.

### Orifice Parameterizations

The block behavior depends on the **Orifice parameterization** parameter:

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parameterization.

### Opening Characteristics

When you set **Orifice type** to **Variable**, the block uses the input at port **L** to control certain parameters. This input is the control signal and it is associated with stroke or lift percent. The control signal ranges in value from 0 to 1. If you specify a lesser or greater value, the block saturates the value to the nearest of the two limits.

The conversion from a control signal to the chosen measure of flow capacity depends on the **Opening characteristic** parameterization. Flow is maximally restricted when the control signal is 0 and minimally restricted when the control signal is 1. In between these values, the flow rate achieved within the resistive element depends on whether the opening parameterization is linear or based on tabulated data:

- **Linear** — The measure of flow capacity is proportional to the control signal at port **L**. The two values vary in tandem until the control signal either drops below 0 or rises above 1. As the control signal rises from 0 to 1, the measure of flow capacity scales from the specified minimum to the specified maximum.

When you set **Orifice parameterization** to **Sonic conductance**, the block treats the critical pressure ratio and subsonic index as constants that are independent of control signal. When you

set **Orifice parameterization** to Cv flow coefficient or Kv flow coefficient, the block treats the parameter **xT pressure differential ratio factor at choked flow** as a constant independent of the control signal.

- **Tabulated** — The block calculates the measure of flow capacity as a function of the control signal at port **L**. This function is based on a one-way lookup table. The tabulated data must be specified so the measure of flow capacity increases monotonically with the control signal.

When you set **Orifice parameterization** to Sonic conductance, the block treats the critical pressure ratio as a function of the control signal and treats the subsonic index as a constant.. When you set **Orifice parameterization** to Cv flow coefficient or Kv flow coefficient, the block treats the parameter **xT pressure differential ratio factor at choked flow** as a function of the control signal.

### Numerical Smoothing

When the **Orifice type** parameter is Variable, the **Opening characteristic** parameter is Linear, and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the control signal from port **L**. Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3 p_{in} F_y x_T},$$

where:

- $F_y$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3F_{\gamma}x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma}x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3}C_v N_6 \sqrt{F_{\gamma} x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{\frac{p_{out}}{p_{in}} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m,$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C \rho_{ref} \sqrt{\frac{T_{ref}}{T_{avg}}} \left[ 1 - \left( \frac{B_{lam} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m \left( \frac{p_{in} - p_{out}}{1 - B_{lam}} \right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is



$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left(\frac{p_{out}}{p_{in}}\right)^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}}}\right]}$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \left[ \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}}\right] \left( p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}} \right)}$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the resistive element is very small and ignores these values. As a result, no amount of fluid can accumulate in the resistive element. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Assumptions and Limitations

- The **Sonic conductance** setting of the **Orifice parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice area** parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Input

#### **L — Orifice opening, unitless**

physical signal

Control signal that specifies the opening of the orifice. In some valves, this represents the stroke or lift percent. The orifice is fully closed at a value of 0 and fully open at a value of 1.

### Dependencies

To enable this parameter, set **Orifice type** to **Variable**.

### Conserving

#### **A — Flow passage**

gas

Gas conserving port associated with the opening through which the flow enters or exits the flow resistance. The block has no intrinsic directionality. The port can serve as the inlet or outlet, depending on the direction of the flow.

#### **B — Flow passage**

gas

Gas conserving port associated with the opening through which the flow enters or exits the flow resistance. The block has no intrinsic directionality. The port can serve as the inlet or outlet, depending on the direction of the flow.

## Parameters

### **Orifice type — Type of orifice**

Variable (default) | Constant

Type of orifice defined by the orifice area. When you set this parameter to **Variable**, the orifice area varies according to the input signal received at port **L**.

### **Orifice parameterization — Parameterization used to specify flow characteristics of orifice**

Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization.
- **Orifice area** — The size of the flow restriction determines the block parameterization.

### **Opening characteristic — Method to convert from control signal to measure of flow capacity**

Linear (default) | Tabulated

Method by which to convert the control signal specified at port **L** to the chosen measure of flow capacity.

#### **Dependencies**

To enable this parameter, set **Orifice type** to Variable.

### **Opening fraction vector — Control signal values at which to specify tabulated parameter data**

0 : 0.2 : 1 (default) | vector of positive numbers

Vector of control signal values at which to specify the chosen measure of flow capacity: **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector**. The control signal is between 0 and 1, with each value corresponding to an opening fraction of the resistive element. The greater the value, the greater the opening and easier the flow.

The opening fractions must increase monotonically across the vector from left to right. The size of this vector must be the same as the **Sonic conductance vector**, **Cv coefficient vector**, **Kv coefficient vector**, or **Orifice area vector** parameter.

#### **Dependencies**

To enable this parameter, set **Orifice type** to Variable, and **Opening characteristic** to Tabulated.

### **Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the control signal specified at port **L** is 1 and restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

#### **Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Cv flow coefficient, and **Opening characteristic** to Linear.

### **xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Cv flow coefficient or Kv flow coefficient.

**Leakage flow fraction – Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, and **Opening characteristic** to Linear.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, and **Opening characteristic** to Linear.

**Cv flow coefficient vector – Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Cv flow coefficient – Flow coefficient**

4 (default) | positive scalar

Value of the constant  $C_v$  flow coefficient. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Cv flow coefficient.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the control signal specified at port **L** is 1 and the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector — Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers

Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Kv flow coefficient, and **Opening characteristic** to Tabulated.

**Kv flow coefficient — Flow coefficient**

3.6 (default) | positive scalar

Value of the constant  $K_v$  flow coefficient. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Kv flow coefficient.

**Maximum sonic conductance — Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the control signal specified at port **L** is 1 and cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Constant and **Orifice parameterization** to Sonic conductance.
- **Orifice type** to Variable, **Orifice parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Sonic conductance.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Sonic conductance.

**ISO reference density — ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Sonic conductance.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12] l/(bar\*s) (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Sonic conductance, and **Opening characteristic** to Tabulated.

**Critical pressure ratio vector — Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Sonic conductance, and **Opening characteristic** to Tabulated.

**Sonic conductance — Measure of flow rate capacity in choked flow regime**

12  $\text{l}/(\text{bar}\cdot\text{s})$  (default) | positive scalar

Ratio, measured at the onset of choking, of the mass flow rate through the resistive element to the product of the upstream pressure and mass density at standard conditions as defined in ISO 8778. This parameter determines the maximum flow rate allowed at a given upstream pressure.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Sonic conductance.

**Maximum orifice area — Flow area corresponding to maximally open component**

$1\text{e-}4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening when the control signal specified at port **L** is 1 and the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Orifice area, and **Opening characteristic** to Linear.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Orifice area.

**Orifice area vector — Vector of orifice opening area values**

[ $1\text{e-}10$ ,  $2\text{e-}05$ ,  $4\text{e-}05$ ,  $6\text{e-}05$ ,  $8\text{e-}05$ ,  $.0001$ ]  $\text{m}^2$  (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable, **Orifice parameterization** to Orifice area, and **Opening characteristic** to Tabulated.

**Orifice area — Area of orifice opening**

$1\text{e-}4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B – Flow area at gas ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

Introduced in R2018a

**Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Orifice parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

**Separate orifice blocks combined into one**

The Orifice (G) block replaces the Orifice ISO 6358 (G) and Variable Orifice ISO 6358 (G). Use the new **Orifice Type** parameter to choose between Constant and Variable.



## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### **C/C++ Code Generation**

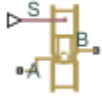
Generate C and C++ code using Simulink® Coder™.

### **See Also**

2-Way Directional Valve (G)

## Orifice with Variable Area Round Holes

Hydraulic variable orifice shaped as set of round holes drilled in sleeve



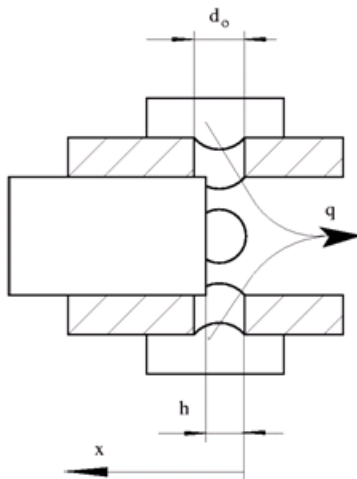
### Library

Orifices

### Description

The block models a variable orifice created by a cylindrical spool and a set of round holes drilled in the sleeve. All the holes are of the same diameter, evenly spread along the sleeve perimeter, and their center lines are located in the same plane. The flow rate through the orifice is proportional to the orifice opening and to the pressure differential across the orifice. The following schematic shows the cross section of an orifice with variable round holes, where

$q$	Flow rate
$h$	Orifice opening
$x$	Spool displacement from initial position
$d_0$	Orifice hole diameter



### Orifice Opening Area

The aggregate opening area provided by the round holes is computed during simulation from the *orifice opening*, a measure of the instantaneous spool position:

$$h = \begin{cases} h_{\text{Min}}, & \text{if } (x_0 + \delta x) \leq h_{\text{Min}} \\ x_0 + \delta x, & \text{else} \end{cases}$$

where:

- $h$  is the orifice opening. The subscript **Min** refers to the minimum value corresponding to a fully closed orifice. This value is calculated during simulation from block parameters.
- $x$  is the spool displacement specified through physical signal port **S**. The subscript  $\theta$  denotes the opening offset specified in the **Initial opening** block parameter.
- $\delta$  is the orifice opening orientation: +1 if positive, -1 if negative. This value is specified in the **Orifice orientation** block parameter.

The minimum orifice opening  $h_{\text{Min}}$  is calculated approximately using the expression:

$$h_{\text{Min}} \approx \frac{d_o}{2} \left[ 1 - \cos \left( \frac{\pi D_{h,\text{Min}}}{2 n_o d_o} \right) \right]$$

where:

- $d_o$  is the diameter of an individual hole. This value is obtained from the **Diameter of round holes** block parameter. The holes are assumed to be identical in size.
- $n_o$  is the number of round holes comprising the orifice. This value is obtained from the **Number of round holes** block parameter.
- $D_{h,\text{Min}}$  is the minimum value of the hydraulic diameter of the orifice as a whole. This value is calculated from the minimum opening area specified in the **Leakage area** block parameter:

$$D_{h,\text{Min}} = \frac{\pi d_o^2}{4}$$

The opening area of the orifice (the sum over the various round holes) is calculated from the conditional expression:

$$A(h) = \begin{cases} A_{\text{Leak}} & \text{for } h \leq 0 \\ \left[ \frac{1}{8} n_o \cdot d_o^2 \left[ 2 \arccos \left( 1 - \frac{2h}{d_o} \right) - \sin \left( 2 \arccos \left( 1 - \frac{2h}{d_o} \right) \right) \right] \right] + A_{\text{Leak}} & \text{for } 0 < h < d_o, \\ A_{\text{Max}} + A_{\text{Leak}} & \text{for } h \geq d_o \end{cases}$$

where:

- $A_{\text{Leak}}$  is the opening area in the fully closed position, when only leakage remains. This value is obtained from the **Leakage area** block parameter.
- $A_{\text{Max}}$  is the opening area in the fully open position, when the holes are open to full capacity. This value is calculated from the number and diameter of the holes:

$$A_{\text{Max}} = n_o \pi \frac{d_o^2}{4}$$

### Orifice Flow Rate

The net flow rate through the orifice is calculated as:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

where:

- $q$  is the volumetric flow rate through the orifice (the sum of the flow rates through the various holes).
- $C_D$  is the discharge coefficient of the orifice. This value is obtained from the **Flow discharge coefficient** block parameter.
- $A$  is the aggregate opening area of the orifice (calculated as a function of the orifice opening  $h$ ).
- $\Delta p$  is the pressure differential from port **A** to port **B**:

$$\Delta p = p_A - p_B,$$

where  $p$  is the gauge pressure through the port indicated in the subscript.

- $p_{Cr}$  is the calculated value of the critical pressure (from port **A** to port **B**) at which the flow is considered to shift between laminar and turbulent regimes.

### Critical Pressure Differential

The calculation of the critical pressure differential varies with the setting of the **Laminar transition specification** block parameter:

- **By pressure ratio** – Obtain the critical pressure differential from the critical pressure ratio:

$$p_{Cr} = (p_{Avg} + p_{Atm})(1 - \beta),$$

where  $\beta$  is the critical pressure ratio, obtained from the **Laminar flow pressure ratio** block parameter, defined as the ratio of the outlet pressure to the inlet pressure at the transition point between laminar and turbulent regimes. The subscript **Atm** denotes the atmospheric value (0.101325 MPa at standard reference conditions) and the subscript **Avg** the average of the gauge pressures at the ports:

$$p_{Avg} = \frac{p_A + p_B}{2},$$

- **By Reynolds number** – Obtain the critical pressure differential from the critical Reynolds number:

$$p_{Cr} = \frac{\rho}{2} \left( \frac{Re_{Cr} \cdot \nu}{C_D \cdot D_H} \right)^2,$$

where  $Re_{Cr}$  is the critical Reynolds number, at which the flow can be said to transition between laminar and turbulent regimes,  $\nu$  is the average of the kinematic viscosities at the ports, and  $D_h$  is the hydraulic diameter of the orifice:

$$D_h = \begin{cases} D_{h,Min}, & \text{if } h \leq h_{Min} \\ d_o + D_{h,Min}, & \text{if } h > d_o \\ \frac{4A}{P}, & \text{else} \end{cases},$$

with  $P$  as the sum of the perimeters of the holes:

$$P = n_o d_o \left[ 2a \cos \left( 1 - \frac{2h}{d_o} \right) + 2a \sin \left( \cos \left[ 1 - \frac{2h}{d_o} \right] \right) \right]$$

## Basic Assumptions and Limitations

- Fluid inertia is ignored.

## Parameters

### Diameter of round holes

Diameter of the orifice holes. The default value is 5e-3 m.

### Number of round holes

Number of holes. The default value is 6.

### Flow discharge coefficient

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.6.

### Initial opening

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.

### Orifice orientation

The parameter is introduced to specify the effect of the orifice control member motion on the valve opening. The parameter can be set to one of two options: `Opens in positive direction` or `Opens in negative direction`. The value `Opens in positive direction` specifies an orifice whose control member opens the valve when it is shifted in the globally assigned positive direction. The parameter is extremely useful for building a multi-orifice valve with all the orifices being controlled by the same spool. The default value is `Opens in positive direction`.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- `Pressure ratio` — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- `Reynolds number` — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics

textbooks. The default value is 10. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-15 \text{ m}^2$ .

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Orifice orientation**

All other block parameters are available for modification.

### **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

### **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

S

Physical signal port to control spool displacement.

The flow rate is positive if fluid flows from port A to port B. Positive signal at the physical signal port S opens or closes the orifice depending on the value of the parameter **Orifice orientation**.

## **Version History**

Introduced in R2006a

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

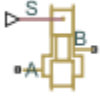
[Annular Orifice](#) | [Constant Area Hydraulic Orifice](#) | [Fixed Orifice](#) | [Orifice with Variable Area Slot](#) | [Variable Area Hydraulic Orifice](#) | [Variable Orifice](#)

## **Topics**

[“Upgrading Simscape Fluids Models Containing Hydraulics \(Isothermal\) Blocks”](#)

## Orifice with Variable Area Slot

Hydraulic variable orifice shaped as rectangular slot



### Library

Orifices

### Description

The block models a variable orifice created by a cylindrical sharp-edged spool and a rectangular slot in a sleeve. The flow rate through the orifice is proportional to the orifice opening and to the pressure differential across the orifice. The flow rate is determined according to the following equations:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

$$\Delta p = p_A - p_B,$$

$$h = x_0 + x \cdot or$$

$$A(h) = \begin{cases} A_{leak} & \text{if } b \cdot h < A_{leak} \\ b \cdot h & \text{otherwise} \end{cases}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A(h)$	Instantaneous orifice passage area
$b$	Width of the orifice slot
$x_0$	Initial opening
$x$	Spool displacement from initial position
$h$	Orifice opening
$or$	Orifice orientation indicator. The variable assumes +1 value if a spool displacement in the globally assigned positive direction opens the orifice, and -1 if positive motion decreases the opening.
$\rho$	Fluid density



$A_{\text{leak}}$	Closed orifice leakage area
$p_{\text{cr}}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{\text{cr}}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = (p_{\text{avg}} + p_{\text{atm}})(1 - B_{\text{lam}})$$

$$p_{\text{avg}} = (p_A + p_B)/2$$

where

$p_{\text{avg}}$	Average pressure between the block terminals
$p_{\text{atm}}$	Atmospheric pressure, 101325 Pa
$B_{\text{lam}}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = \frac{\rho}{2} \left( \frac{Re_{\text{cr}} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Instantaneous orifice hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{\text{cr}}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S opens or closes the orifice depending on the value of the parameter **Orifice orientation**.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.

## Parameters

### Orifice width

The width of the rectangular slot. The default value is 1e-2 m.

**Flow discharge coefficient**

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Initial opening**

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.

**Orifice orientation**

The parameter is introduced to specify the effect of the orifice control member motion on the valve opening. The parameter can be set to one of two options: `Opens in positive direction` or `Opens in negative direction`. The value `Opens in positive direction` specifies an orifice whose control member opens the valve when it is shifted in the globally assigned positive direction. The parameter is extremely useful for building a multi-orifice valve with all the orifices being controlled by the same spool. The default value is `Opens in positive direction`.

**Laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- `Pressure ratio` — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- `Reynolds number` — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

**Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Orifice orientation**

All other block parameters are available for modification.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

S

Physical signal port to control spool displacement.

The flow rate is positive if fluid flows from port A to port B. Positive signal at the physical signal port S opens or closes the orifice depending on the value of the parameter **Orifice orientation**.

## Version History

**Introduced in R2006a**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Annular Orifice | Constant Area Hydraulic Orifice | Fixed Orifice | Orifice with Variable Area Round Holes | Variable Area Hydraulic Orifice | Variable Orifice

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Orifice (2P)

Constant- or variable-area orifice in a two-phase fluid network

**Library:** Simscape / Fluids / Two-Phase Fluid / Valves & Orifices



### Description

The Orifice (2P) block models pressure loss due to a constant or variable area orifice in a two-phase fluid network. The orifice can be constant or variable. When **Orifice type** is set to **Variable**, the physical signal at port **S** sets the position of the control member, which opens and closes the orifice.

Fluid properties inside the valve are calculated from inlet conditions. There is no heat exchange between the fluid and the environment, and therefore phase change inside the orifice only occurs due to a pressure drop or a propagated phase change from another part of the model.

A number of block parameters are based on nominal operating conditions, which correspond to the orifice rated performance, such as a specification on a manufacturer datasheet.

#### Constant Area

When you set **Orifice type** to **Constant**, the orifice has a constant area. The mass flow rate through the orifice is:

$$\dot{m}_A = \dot{m}_{nom} \left[ \sqrt{\frac{v_{nom}}{2\Delta p_{nom}}} \right] \sqrt{\frac{2}{v_{in}}} \frac{\Delta p}{(\Delta p^2 + \Delta p_{lam}^2)^{0.25}},$$

where:

- $\Delta p$  is the pressure drop over the orifice,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure transition threshold between laminar and turbulent flow, which is calculated from the **Laminar flow pressure ratio**,  $B_{lam}$ :

$$\Delta p_{lam} = \frac{(p_A + p_B)}{2} (1 - B_{lam}).$$

- $\dot{m}_{nom}$  is the **Nominal mass flow rate**.
- $\Delta p_{nom}$  is the **Nominal pressure drop rate**.
- $v_{nom}$  is the nominal inlet specific volume. This value is determined from the fluid properties tabulated data based on the **Nominal inlet condition specification** parameter.
- $v_{in}$  is the inlet specific volume.

#### Variable Area

When you set **Orifice type** to **Variable**, the block is configured for a variable opening, which is set by the control member position at **S**. The block calculates the mass flow rate through the variable-area orifice as:

$$\dot{m}_A = \lambda \dot{m}_{nom} \left[ \sqrt{\frac{v_{nom}}{2\Delta p_{nom}}} \right] \sqrt{\frac{2}{v_{in}}} \frac{\Delta p}{(\Delta p^2 + \Delta p_{lam}^2)^{0.25}},$$

where  $\lambda$  is the orifice opening fraction.

### Control Member Displacement

The orifice opening, which is expressed as a fraction of the total orifice open area, is determined by the input signal at **S**, the **Control member travel between closed and open orifice** parameter,  $\Delta S$ , and a leakage value that improves numerical stability when the orifice is closed:

$$\lambda = \varepsilon(1 - f_{leak})\frac{(S - S_{min})}{\Delta S} + f_{leak},$$

where:

- $\varepsilon$  is the **Opening orientation**. This value is +1 when the setting is Positive control member displacement opens orifice and -1 when the setting is Negative control member displacement opens orifice.
- $f_{leak}$  is the **Closed orifice leakage as a fraction of nominal flow**.
- $S_{min}$  is the **Control member position at closed orifice**.

### Fluid Specific Volume Dynamics

When the fluid at the orifice inlet is a liquid-vapor mixture, the block calculates the specific volume as:

$$v_{in} = (1 - x_{dyn})v_{liq} + x_{dyn}v_{vap},$$

where:

- $x_{dyn}$  is the inlet vapor quality. The block applies a first-order lag to the inlet vapor quality of the mixture.
- $v_{liq}$  is the liquid specific volume of the fluid.
- $v_{vap}$  is the vapor specific volume of the fluid.

If the inlet fluid is liquid or vapor,  $v_{in}$  is the respective liquid or vapor specific volume.

### Vapor Quality Lag

If the inlet vapor quality is a liquid-vapor mixture, the block applies a first-order time lag:

$$\frac{dx_{dyn}}{dt} = \frac{x_{in} - x_{dyn}}{\tau},$$

where:

- $x_{dyn}$  is the dynamic vapor quality.
- $x_{in}$  is the current inlet vapor quality.
- $\tau$  is the **Inlet phase change time constant**.

If the inlet fluid is a subcooled liquid or superheated vapor,  $x_{dyn}$  is equal to  $x_{in}$ .

### Mass Balance

Mass is conserved in the orifice:

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

### Energy Balance

Energy is conserved in the orifice:

$$\Phi_A + \Phi_B = 0,$$

where:

- $\Phi_A$  is the energy flow at port **A**.
- $\Phi_B$  is the energy flow at port **B**.

### Assumptions and Limitations

- The block does not model pressure recovery downstream of the valve.
- There is no heat exchange between the valve and the environment.
- The block does not model choked flow.

## Ports

### Conserving

#### A – Fluid port

two-phase fluid

Fluid entry or exit port.

#### B – Fluid port

two-phase fluid

Fluid entry or exit port.

### Input

#### S – Control member position

physical signal

Control member position that sets the orifice opening.

### Dependencies

To enable this port, set **Orifice type** to **Variable**.

## Parameters

### Orifice type – Constant or variable orifice

Variable (default) | Constant

Type of orifice. When set to **Variable**, the orifice area varies according to the input signal received at port **S**.

**Nominal mass flow rate — Rated mass flow rate**

0.1 kg/s (default) | positive scalar

Typical, rated, or design mass flow rate through a constant orifice.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant.

**Nominal pressure drop — Rated pressure drop**

0.001 MPa (default) | positive scalar

Typical, rated, or design pressure drop through a constant orifice.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant.

**Control member position at closed orifice — Control member offset**

0 m (default) | positive scalar

Control member offset, or the value at **S** when the orifice is fully closed.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Control member travel between closed and open orifice — Control member stroke**

5e-3 m (default) | positive scalar

Distance the control member travels between a closed and open orifice. When you set **Opening orientation** to Positive control member displacement opens orifice, the orifice is fully open at the sum of the **Control member position at closed orifice** and **Control member travel between closed and open orifice** parameters. When you set **Opening orientation** to Negative control member displacement opens orifice, the orifice is fully open at the difference between the **Control member position at closed orifice** and **Control member travel between closed and open orifice** parameters.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Opening orientation — Direction of displacement that opens the orifice**

Positive control member displacement opens orifice (default) | Negative control member displacement opens orifice

Direction of member displacement that opens a variable orifice. A positive orientation means that an increase in the signal at **S** opens the orifice. A negative orientation means that a decrease in the signal at **S** opens the orifice.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Nominal mass flow rate at maximum opening — Rated mass flow rate**

0.1 kg/s (default) | positive scalar

Mass flow rate through a fully open orifice under typical, design, or rated conditions.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Nominal pressure drop at maximum opening — Rated pressure drop**

0.001 MPa (default) | positive scalar

Pressure drop over a fully open orifice under typical, design, or rated conditions.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Nominal inlet condition specification — Method of determining inlet fluid state**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Method of determining inlet fluid state. The orifice nominal inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet pressure — Inlet fluid pressure**

0.101325 MPa (default) | positive scalar

Inlet pressure in nominal conditions. The inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet temperature — Fluid temperature**

293.15 K (default) | positive scalar

Inlet fluid temperature in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Inlet vapor quality mass fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet mixture vapor quality by mass fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor quality.

**Nominal inlet vapor void fraction — Inlet volume fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet mixture volume fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor void fraction.



**Nominal inlet specific enthalpy – Inlet fluid specific enthalpy**

1500 kJ/kg (default) | positive scalar

Inlet specific enthalpy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific enthalpy.

**Nominal inlet specific internal energy – Inlet specific internal energy**

1500 kJ/kg (default) | positive scalar

Inlet specific internal energy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific internal energy.

**Cross-sectional area at ports A and B – Valve port areas**0.01 m<sup>2</sup> (default) | positive scalar

Area of the orifice ports **A** and **B**.

**Closed orifice leakage as a fraction of nominal flow – Fractional flow when orifice is closed**

1e-6 (default) | positive scalar

Fractional flow rate through the orifice when it is fully closed. This parameter contributes to numerical stability by maintaining continuity in the fluid network.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regions.

**Laminar flow pressure ratio – Laminar-turbulent transition pressure ratio**

0.999 (default) | positive scalar

Ratio of the orifice outlet pressure to orifice inlet pressure at which the fluid transitions between the laminar and turbulent regimes. The pressure loss corresponds to the mass flow rate linearly in laminar flows and quadratically in turbulent flows.

**Inlet phase change time constant – Lag for mixture specific volume**

0.1 s (default) | positive scalar

Time lag for liquid-vapor mixtures in computing the fluid specific volume. This parameter does not influence the specific volume when the inlet fluid is a fully supercooled liquid or fully superheated vapor.

**Version History**

**Introduced in R2021a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Check Valve (2P) | Pressure-Reducing Valve (2P) | Pressure Relief Valve (2P) | Thermostatic Expansion Valve (2P)

## P-H Diagram (2P)

Thermodynamic scope for two-phase fluid networks

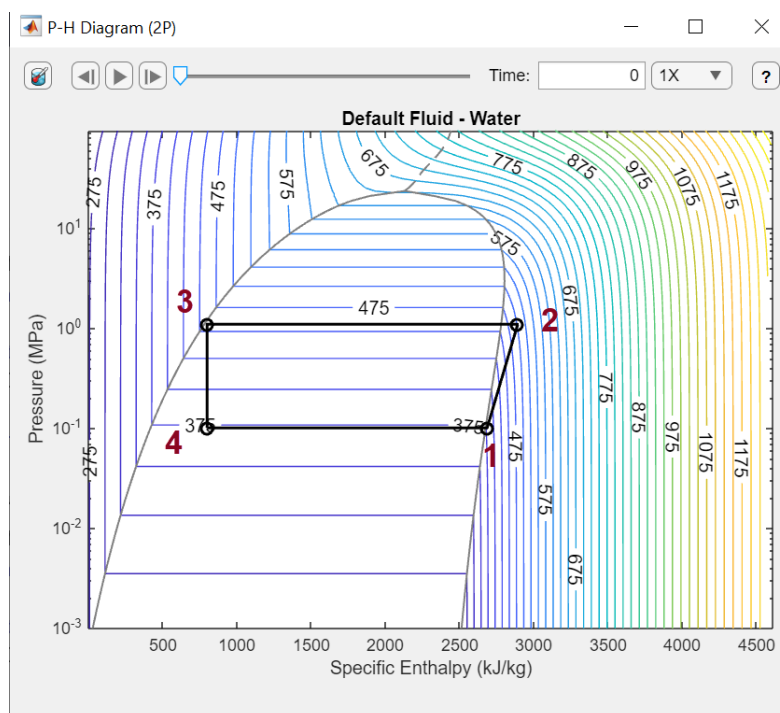
**Library:** Simscape / Fluids / Two-Phase Fluid / Utilities



### Description

The P-H Diagram (2P) block plots a p-h diagram of the pressure with respect to the specific enthalpy of a thermodynamic, two-phase fluid. A p-h diagram indicates the fluid state at key points during a thermodynamic cycle.

The plot units are MPa for pressure, kJ/kg for specific enthalpy, and K for the temperature contours.



Each numbered point on the diagram indicates the fluid state after a dynamic process in the refrigeration cycle:

- 1 Cool vapor at low pressure
- 2 Hot vapor at high pressure
- 3 Hot liquid at high pressure
- 4 Mixed vapor and liquid at low pressure

To use the P-H Diagram (2P) block:


- 1 Place a Thermodynamic Properties Sensor (2P) and a Pressure & Internal Energy Sensor (2P) block at each location you want to monitor.

---

**Note** The Pressure & Internal Energy Sensor (2P) block measures a differential pressure. Connect port **A** to the monitor point and port **B** to an Absolute Reference (2P) block.

---

- 2 Convert the Simscape physical signals to Simulink signals with a PS-Simulink Converter block.
- 3 Use a Mux block to combine the pressure signals. Connect the output signal to the P-H Diagram (2P) **p** port.
- 4 Use a Mux block to combine the converted specific enthalpy signals and connect the output signal to the **h** port.
- 5 Before running the simulation, double-click the P-H Diagram (2P) block, then click the Select



fluid properties button  to set the network fluid properties.

If you do not select the fluid properties, the block uses the default two-phase network fluid, which is water.

### P-H Diagram Playback

You can also replay the animation from the most recent simulation. After running the model, double-click the block and use the buttons at the top of the window to control the animation. Use the drop-down menu to the right of the **Time** field to control the rate of the playback. The replay controls are disabled before you run a simulation, when the model is loaded, and when the simulation is running.

Use the playback slider or **Time** field to control the simulation cycle. If you enter a time that is not a model time step, the block displays the next closest time step.

To save the current iteration of the plot, point to the plot area. From the icons in the top-right corner of the plot, click the Export icon  and select the Save As button  to save the plot.

## Ports

### Input

#### **p** — Pressure, MPa

vector

Vector of pressures. The vector must have same number of elements as the enthalpy signal at port **h**

#### **h** — Specific enthalpy, kJ/kg

vector

Vector of specific enthalpies. The vector must have same number of elements as the pressure signal at port **p**.

## Version History

Introduced in R2021a

**Access playback capabilities**

Use the controls at the top of the figure window to control and replay the animation from the most recent simulation.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

This block can be used for simulation visibility in systems that generate code, but is not included in the generated code.

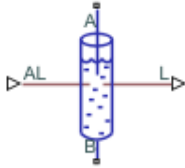
**See Also**

Thermostatic Expansion Valve (2P)

## Partially Filled Pipe (IL)

Pipe with variable liquid volume in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Partially Filled Pipe (IL) block models a pipe with the capacity for varying internal liquid levels. The pipe may also become completely dry during simulation.

In addition to liquid connections at ports **A** and **B**, port **AL** receives the inlet liquid level from connected blocks as a physical signal. If the value at **AL** is greater than zero, **A** is submerged. If the value at **AL** is less than or equal to zero, the port is exposed. The pipe liquid level is transmitted as a physical signal to connecting blocks at port **L**.

Port **A** is always higher than port **B**. If port **A** becomes exposed, the pipe can be filled through port **B**. When fluid enters the pipe through port **B**, the mass flow rate through port **A** is 0 until the pipe is fully filled, at which point  $\dot{m}_A = -\dot{m}_B$ .

### When to Use the Partially Filled Pipe (IL) Block

This block can be used in conjunction with the Tank (IL) block when fluid levels are expected to fall below the tank inlet. Multiple Partially Filled Pipe (IL) blocks can also be connected in series or parallel. However, because a partially filled pipe can only be filled at port **B**, if port **A** of one block in a parallel configuration becomes exposed, it may not be possible to refill this pipe if its connection at port **B** cannot refill the pipe.

### Pressure Loss Over the Pipe

The pressure differential over the pipe,  $p_A - p_B$ , comprises losses due to wall friction and hydrostatic pressure differences between the liquid surface height and the liquid height at port **A**:

$$p_A - p_B = \Delta p_{loss} + \Delta p_{elev}.$$

Friction losses depend on the fluid regime in the pipe. If the flow is laminar, the friction losses are:

$$\Delta p_{loss} = \frac{-\dot{m}_B \nu f_s \hat{L}}{2D_h^2 A^2},$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $f_s$  is the **Laminar friction constant for Darcy friction factor**.

- $\widehat{L}$  is the sum of the pipe length and its **Aggregate equivalent length of local resistances**, in proportion to the pipe fill level:  $\widehat{L} = (L + L_{add})\frac{l}{l_{\max}}$ .
- $l, l_{\max}$  are the liquid level and the **Elevation drop from port A to port B**, respectively.
- $D_h$  is the pipe hydraulic diameter. If the pipe cross-section is not circular, the hydraulic diameter is the equivalent circular diameter.

If the flow is turbulent, the friction losses are:

$$\Delta p_{\text{loss}} = \frac{-\dot{m}_B |\dot{m}_B| f \widehat{L}}{2\rho D_h^2 A^2}.$$

$f$  is the Darcy friction factor for turbulent flows, which is determined by the empirical Haaland correlation:

$$f = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}} + \left( \frac{\varepsilon}{3.7 D_h} \right)^{1.11} \right] \right\}^{-2},$$

where  $\varepsilon$  is the **Internal surface absolute roughness**. The Reynolds number is based on the mass flow rate at port **B** and the pipe hydraulic diameter.

The hydrostatic pressure difference is  $\Delta p_{\text{elev}} = \rho g l$ .

### Mass Flow Rate

The flow in the pipe is dictated by the internal fluid level and the conditions at port **B**. The pipe can be filled or drained at **B** if the pipe is partially empty. If the pipe is fully filled,  $\dot{m}_A = \dot{m}_B$ , and mass is conserved:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass of fluid in the pipe is determined by the relative fill level of the pipe:

$$M = \rho A L \frac{l}{l_{\max}}.$$

### Assumptions and Limitations

This block does not account for dynamic compressibility or fluid inertia, and does not model the dynamics of air (or second liquid) in the pipe.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Fluid entry or exit to the pipe. Port **A** is always higher than port **B**. When port **A** is submerged,  $\dot{m}_A = \dot{m}_B$ . When port **A** is exposed,  $\dot{m}_A = 0$ .

#### B – Liquid port

isothermal liquid

Fluid entry or exit to the pipe. Port **A** is always higher than port **B**. When port **A** is submerged,  $\dot{m}_A = \dot{m}_B$ . When port **A** is exposed, any flow into or out of port **B** changes the liquid level in the pipe. A dry or partially dry pipe can only be filled through port **B**.

### Input

#### **AL — Relative liquid level of connected block, m**

physical signal

Relative liquid level of the connected block in m, specified as a physical signal. If the signal at **AL** is positive, the pipe end is submerged. Otherwise the port is exposed.

### Output

#### **L — Pipe liquid level, m**

physical signal

Liquid level in the pipe in m, returned as a physical signal..

## Parameters

### Geometry

#### **Pipe length — Pipe length**

5 m (default) | positive scalar

Pipe length.

#### **Cross-sectional area — Pipe cross-sectional area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the pipe.

#### **Hydraulic diameter — Hydraulic diameter**

0.1128 m (default) | positive scalar

Hydraulic diameter used in calculations of the pipe Reynolds number. For non-circular pipes, the hydraulic diameter is the effective diameter of the fluid in the pipe. For circular pipes, the hydraulic diameter and pipe diameter are the same.

#### **Elevation drop from port A to port B — Vertical distance between A and B**

5 m (default) | positive scalar

Vertical change in elevation of the pipe. Port **A** is always higher than port **B**.

#### **Initial liquid level — Starting liquid level**

5 m (default) | positive scalar

Liquid level in the pipe at the beginning of the simulation.

#### **Liquid level below zero — Whether to notify if no liquid is in pipe**

Error (default) | None | Warning



Whether to notify if no liquid is in the pipe. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

### **Gravitational acceleration — Acceleration of gravity**

9.81 m/s<sup>2</sup> (default) | positive scalar

Acceleration of gravity constant.

### **Friction**

#### **Aggregate equivalent length of local resistances — Contribution of pipe geometry to hydraulic losses**

1 m (default) | positive scalar

Length of pipe that would produce the equivalent hydraulic losses as would a pipe with bends, area changes, or other non-uniform attributes.

#### **Internal surface absolute roughness — Pipe wall roughness**

15e-6 m (default) | positive scalar

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

#### **Laminar flow upper Reynolds number limit — Laminar flow upper threshold**

2000 (default) | positive scalar

Upper Reynolds number limit to laminar flow. Beyond this number, the fluid regime is transitional and approaches the turbulent regime and becomes fully turbulent at the **Turbulent flow lower Reynolds number limit**.

#### **Turbulent flow lower Reynolds number limit — Turbulent flow lower threshold**

4000 (default) | positive scalar

Lower Reynolds number limit for turbulent flow. Below this number, the flow regime is transitional and approaches laminar flow and becomes fully laminar at the **Laminar flow upper Reynolds number limit**.

#### **Laminar friction constant for Darcy friction factor — Pipe friction constant for laminar flows**

64 (default) | positive scalar

Pipe friction constant for laminar flows. The laminar Darcy friction factor captures the contribution of wall friction in pressure loss calculations.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

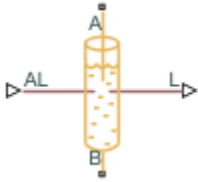
**See Also**

Pipe (IL) | Tank (IL)

## Partially Filled Pipe (TL)

Pipe with variable liquid volume in an thermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Partially Filled Pipe (TL) block represents a pipe with the capacity for varying internal liquid levels. The pipe may also become completely dry during simulation.

In addition to liquid connections at ports **A** and **B**, port **AL** receives the inlet liquid level from connected blocks as a physical signal. If the value at **AL** is greater than zero, **A** is submerged. If the value at **AL** is less than or equal to zero, the port is exposed. The pipe liquid level is transmitted as a physical signal to connecting blocks at port **L**.

Port **A** is always higher than port **B**. If port **A** becomes exposed, the pipe can be filled through port **B**. When fluid enters the pipe through port **B**, the mass flow rate through port **A** is 0 until the pipe is fully filled, at which point  $\dot{m}_A = -\dot{m}_B$ .

### When to Use the Partially Filled Pipe (TL) Block

This block can be used in conjunction with the Tank (TL) block when fluid levels are expected to fall below the tank inlet. Multiple Partially Filled Pipe (TL) blocks can also be connected in series or parallel. However, because the block can only be filled at port **B**, if port **A** of one block in a parallel configuration becomes exposed, it may not be possible to refill this pipe if its connection at port **B** cannot refill the pipe.

### Pressure Loss Over the Pipe

The pressure differential over the pipe,  $p_A - p_B$ , comprises losses due to wall friction and hydrostatic pressure differences between the liquid surface height and the liquid height at port **A**:

$$p_A - p_B = \Delta p_{loss} + \Delta p_{elev}.$$

Friction losses depend on the fluid regime in the pipe. If the flow is laminar, the friction losses are:

$$\Delta p_{loss} = \frac{-\dot{m}_B \nu f_s \widehat{L}}{2D_h^2 A^2},$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $f_s$  is the **Laminar friction constant for Darcy friction factor**.

- $\widehat{L}$  is the sum of the pipe length and its **Aggregate equivalent length of local resistances**, in proportion to the pipe fill level:  $\widehat{L} = (L + L_{add})\frac{l}{l_{\max}}$ .
- $l, l_{\max}$  are the liquid level and the **Elevation drop from port A to port B**, respectively.
- $D_h$  is the pipe hydraulic diameter. If the pipe cross-section is not circular, the hydraulic diameter is the equivalent circular diameter.

If the flow is turbulent, the friction losses are:

$$\Delta p_{\text{loss}} = \frac{-\dot{m}_B |\dot{m}_B| f \widehat{L}}{2\rho D_h^2 A^2}.$$

$f$  is the Darcy friction factor for turbulent flows, which is determined by the empirical Haaland correlation:

$$f = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}} + \left( \frac{\varepsilon}{3.7 D_h} \right)^{1.11} \right] \right\}^{-2},$$

where  $\varepsilon$  is the **Internal surface absolute roughness** parameter. The Reynolds number is based on the mass flow rate at port **B** and the pipe hydraulic diameter.

The hydrostatic pressure difference is  $\Delta p_{\text{elev}} = \rho g l$ .

### Mass Flow Rate

The flow in the pipe is dictated by the internal fluid level and the conditions at port **B**. The pipe can be filled or drained at **B** if the pipe is partially empty. If the pipe is fully filled,  $\dot{m}_A = \dot{m}_B$ , and mass is conserved:

$$\dot{m}_A + \dot{m}_B = 0.$$

The block determines the mass of fluid in the pipe by the relative fill level of the pipe:

$$M = \rho A L \frac{l}{l_{\max}}.$$

### Energy Balance

The block balances energy flow such that when port **A** is submerged,

$$M c_v \frac{dT}{dt} = \phi_A + \phi_B - \dot{m}_B g l.$$

When port **A** is exposed,

$$M c_v \frac{dT}{dt} = \phi_A + \phi_B - \dot{m}_B h - \dot{m}_B g l,$$

where  $c_v$  is the specific heat at constant volume,  $T$  is the fluid temperature, and  $h$  is the specific enthalpy.

## Assumptions and Limitations

This block does not account for dynamic compressibility or fluid inertia, and does not model the dynamics of air (or second liquid) in the pipe.

## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port. Port **A** is always higher than port **B**. When port **A** is submerged,  $\dot{m}_A = \dot{m}_B$ . When port **A** is exposed,  $\dot{m}_A = 0$ .

#### B — Liquid port

thermal liquid

Thermal liquid conserving port. Port **A** is always higher than port **B**. When port **A** is submerged,  $\dot{m}_A = \dot{m}_B$ . When port **A** is exposed, any flow into or out of port **B** changes the liquid level in the pipe. A dry or partially dry pipe can only be filled through port **B**.

### Input

#### AL — Relative liquid level of connected block, m

physical signal

Relative liquid level of the connected block in m, specified as a physical signal. If the signal at **AL** is positive, the pipe end is submerged. Otherwise the port is exposed.

### Output

#### L — Pipe liquid level, m

physical signal

Liquid level in the pipe in m, returned as a physical signal..

## Parameters

### Geometry

#### Pipe length — Pipe length

5 m (default) | positive scalar

Pipe length.

#### Cross-sectional area — Pipe cross-sectional area

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the pipe.

#### Hydraulic diameter — Hydraulic diameter

0.1128 m (default) | positive scalar

Hydraulic diameter used in calculations of the pipe Reynolds number. For non-circular pipes, the hydraulic diameter is the effective diameter of the fluid in the pipe. For circular pipes, the hydraulic diameter and pipe diameter are the same.

**Elevation drop from port A to port B – Vertical distance between A and B**

5 m (default) | positive scalar

Vertical change in elevation of the pipe. Port **A** is always higher than port **B**.

**Initial liquid level – Starting liquid level**

5 m (default) | positive scalar

Liquid level in the pipe at the beginning of the simulation.

**Liquid level below zero – Whether to notify if no liquid is in pipe**

Error (default) | None | Warning

Whether to notify if no liquid is in the pipe. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

**Gravitational acceleration – Acceleration of gravity**

9.81 m/s<sup>2</sup> (default) | positive scalar

Acceleration of gravity constant.

**Friction****Aggregate equivalent length of local resistances – Contribution of pipe geometry to hydraulic losses**

1 m (default) | positive scalar

Length of pipe that would produce the equivalent hydraulic losses as would a pipe with bends, area changes, or other non-uniform attributes.

**Internal surface absolute roughness – Pipe wall roughness**

15e-6 m (default) | positive scalar

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

**Laminar flow upper Reynolds number limit – Laminar flow upper threshold**

2000 (default) | positive scalar

Upper Reynolds number limit to laminar flow. Beyond this number, the fluid regime is transitional and approaches the turbulent regime and becomes fully turbulent at the **Turbulent flow lower Reynolds number limit**.

**Turbulent flow lower Reynolds number limit – Turbulent flow lower threshold**

4000 (default) | positive scalar

Lower Reynolds number limit for turbulent flow. Below this number, the flow regime is transitional and approaches laminar flow and becomes fully laminar at the **Laminar flow upper Reynolds number limit**.

**Laminar friction constant for Darcy friction factor – Pipe friction constant for laminar flows**

64 (default) | positive scalar

Pipe friction constant for laminar flows. The laminar Darcy friction factor captures the contribution of wall friction in pressure loss calculations.

**Initial Conditions****Initial liquid temperature – Liquid temperature at start of simulation**

293.15 K (default)

Liquid temperature at the beginning of the simulation.

**Version History****Introduced in R2022a****Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

## Partially Filled Vertical Pipe LP

Partially filled vertical pipe connecting two tanks



### Library

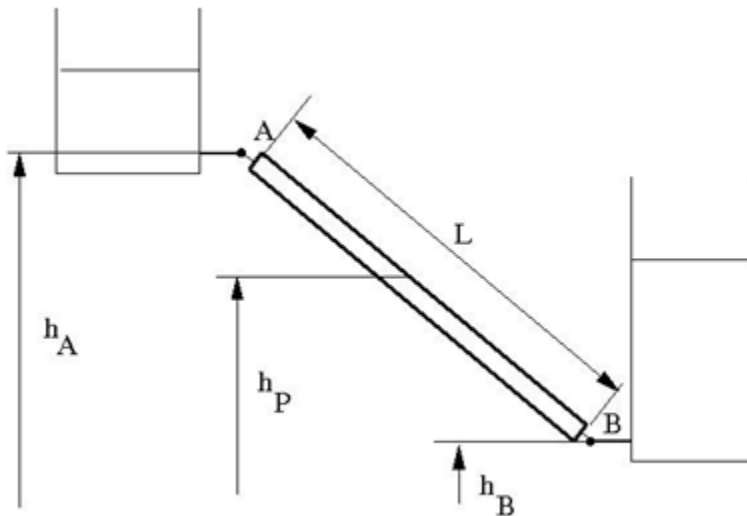
Low-Pressure Blocks

### Description

The Partially Filled Vertical Pipe LP block models a vertical pipe connecting two tanks. The block takes into account the possibility that the top tank gets emptied, and therefore the top port of the pipe can be exposed. The fluid level in the pipe then settles at some intermediate position, depending on pressures at both ports.

The following schematic diagram shows two tanks connected by a partially filled vertical pipe, where:

- $h_A$  and  $h_B$  are the elevations of ports A and B, respectively
- $h_P$  is the fluid level in the pipe
- $L$  is the length of the pipe



The tank is assumed to be empty when fluid volume becomes less than a specified value. If the upstream tank is emptied, the flow rate through port A is assumed to be 0, and the tank pressurization pressure propagates through port A to the pipe. When pressure increases at the bottom port B, the fluid flows upstream. After the pipe is completely filled, the fluid can start filling the top tank.



You must connect port A to a component that provides data on fluid volume (such as the Reservoir block or any of the tank blocks). Port A elevation must be greater than port B elevation.

You can connect port B to any hydraulic component, with one restriction: the component must keep the port submerged at all times.

The pipe hydraulic resistance is proportional to the length of fluid in the pipe (wet length). The shorter the wet length, the lower the resistance. To avoid zero resistance as wet length approaches 0, the volume of fluid in the pipe is limited to the same minimum value as the tank. After the minimum volume is reached, the flow rate through port B is assumed to be 0.

It is a good practice to connect port B either to another tank or to a pressure source. When you connect it to a pressure source, it is good practice to insert some hydraulic resistance (fixed orifice, valve, and so on) between the pipe and the source, to avoid zero resistance.

The block models pipes with circular and noncircular cross sections. The block accounts for friction losses, variable fluid level in the pipe, and resulting variable heads at the ports. The block is based on the assumption of steady-state fluid momentum conditions. For additional information, see “Basic Assumptions and Limitations” on page 1-1285. To account for local resistances (such as bends, fittings, inlet and outlet losses, and so on), convert the resistances into their equivalent lengths, sum up all the resistances to obtain their aggregate length, and then add this length to the pipe geometrical length. The ratio between the added and the current wet length of the pipe is maintained constant as the pipe is emptied or filled with fluid.

Flow rates through the pipe ports are computed individually because they are different when the top port is exposed. The flow rates are proportional to the flow-regime-dependent friction factor and the pressure differential. The friction factor in turbulent regime is determined with the Haaland approximation [1 on page 1-1287]:

$$f = \frac{1}{\left(-1.8 \log_{10} \left( \frac{6.9}{Re} + \left( \frac{k/D_H}{3.7} \right)^{1.11} \right)\right)^2}$$

$$Re = \frac{q \cdot D_H}{A \cdot \nu}$$

where

$f$	Friction factor
$k$	Height of the roughness on the pipe internal surface
$Re$	Reynolds number
$q$	Flow rate
$D_H$	Pipe hydraulic diameter
$A$	Pipe cross-sectional area
$\nu$	Fluid kinematic viscosity

At laminar regime, the friction factor is determined as

$$f = \frac{S}{Re}$$

where  $s$  is the geometrical shape factor, or Poiseuille number [1 on page 1-1287], defined as a function of the Fanning factor for various noncircular shapes: rectangle, concentric annulus, ellipse, and circular sector.

The friction factor during the transition from laminar to turbulent regimes is determined with the linear interpolation between extreme points of the regimes. As a result of these assumptions, the pipe is simulated according to the following equations:

$$q_A = \begin{cases} 0 & \text{for } p > = 0, V < V_{\min} \\ A \sqrt{\frac{1}{f}} \frac{D_H}{L_{ef}} \sqrt{\frac{2}{\rho}} \cdot p & \text{for } p > = 0, V > = V_{\min}, Re > = Re_{cr} \\ 2 \cdot A \cdot \frac{D_H^2}{s \cdot \nu \cdot \rho \cdot L_{ef}} \cdot p & \text{for } p > = 0, V > = V_{\min}, Re < Re_{cr} \\ 0 & \text{for } p < 0, L_F < = L \\ 2 \cdot A \cdot \frac{D_H^2}{s \cdot \nu \cdot \rho \cdot L_{ef}} \cdot p & \text{for } p < 0, L_F > L, Re < Re_{cr} \\ A \sqrt{\frac{1}{f}} \frac{D_H}{L_{ef}} \sqrt{\frac{2}{\rho}} \cdot |p| & \text{for } p < 0, L_F > L, Re > = Re_{cr} \end{cases}$$

$$q_B = \begin{cases} 0 & \text{for } p > = 0, V_F < V_{\min} \\ A \sqrt{\frac{1}{f}} \frac{D_H}{L_{ef}} \sqrt{\frac{2}{\rho}} \cdot |p| \cdot \text{sign}(p) & \text{for } p > = 0, V_F > = V_{\min}, Re > = Re_{cr} \\ 2 \cdot A \cdot \frac{D_H^2}{s \cdot \nu \cdot \rho \cdot L_{ef}} \cdot p & \text{for } p > = 0, V_F > = V_{\min}, Re < Re_{cr} \end{cases}$$

$$q_A - q_B = \frac{dV_p}{dt}$$

$$L_F = \frac{V_p}{A}$$

$$L_{ef} = L_F \left( 1 + \frac{L_{ad}}{L} \right)$$

$$h_p = L_F \frac{h_A - h_B}{L}$$

$$p = p_A - p_B + \rho \cdot g \cdot h_p$$

where

$q_A, q_B$	Flow rates through port A and B, respectively
$p_A, p_B$	Pressures at port A and B, respectively
$h_A, h_B$	Port A and port B elevations, respectively
$L$	Geometrical pipe length
$L_{ad}$	Aggregate equivalent length of local resistances

$L_F$	Pipe wet length
$L_{ef}$	Effective pipe length
$\rho$	Fluid density
$p$	Pressure differential across the pipe
$V$	Fluid volume in the upstream tank
$V_p$	Volume of fluid in the pipe
$V_{min}$	Minimum volume of fluid in the tank, or in the pipe. If $V$ becomes less than $V_{min}$ , then the upstream tank is considered empty, the flow rate through port A is assumed to be 0, and the tank pressurization pressure propagates through port A to the pipe. If $V_p$ becomes less than $V_{min}$ , then the pipe is considered empty and the flow rate through port B is assumed to be 0.
$h_p$	Fluid elevation in the pipe
$Re_{cr}$	Critical Reynolds number
$g$	Gravity acceleration

Flow rate A is considered positive when fluid flows into the pipe. Flow rate B is considered positive when fluid flows out of the pipe.

## Basic Assumptions and Limitations

- The block is based on the assumption of steady-state fluid momentum conditions.
- Fluid inertia and fluid compressibility are not taken into account.
- Flow is assumed to be fully developed along the pipe length, therefore the end effects are not considered.
- To account for local resistances in the pipe, you must convert the resistances into their equivalent lengths, sum them up to obtain their aggregate length, and then add this aggregate length to the pipe geometrical length.
- The elevation of port A must be greater than that of port B.
- Port A must be connected to the hydraulic port of the top tank. The fluid volume in the top tank must be input into the Partially Filled Vertical Pipe LP block through the physical signal port V. If you use one of the standard Simscape Fluids reservoir or tank blocks, connect its physical output port directly to the input port V. If you use a custom tank block, it must have a port that exports fluid volume in the tank as a physical signal, and you must connect this output port to the input port V.
- Port B must not be exposed.
- The friction factor at turbulent regime is computed with the Haaland approximation.
- The friction factor at laminar regime is determined as the Poiseuille number divided by the Reynolds number.
- The friction factor during transition from laminar to turbulent regime is computed with the linear interpolation.

## Parameters

- “Basic Parameters Tab” on page 1-1286

- “Vertical Position Tab” on page 1-1287

## **Basic Parameters Tab**

### **Pipe type**

The type of pipe cross section: **Circular** or **Noncircular**. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is **Circular**.

### **Pipe internal diameter**

Pipe internal diameter. The parameter is available if **Pipe type** is set to **Circular**. The default value is 0.01 m.

### **Noncircular pipe cross-sectional area**

Pipe cross-sectional area. The parameter is available if **Pipe type** is set to **Noncircular**. The default value is 0.08 m<sup>2</sup>.

### **Noncircular pipe hydraulic diameter**

Hydraulic diameter of the pipe cross section. The parameter is available if **Pipe type** is set to **Noncircular**. The default value is 0.1 m.

### **Geometrical shape factor**

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on [1 on page 1-1287]. The default value is 64, which corresponds to a pipe with a circular cross section.

### **Pipe length**

Pipe geometrical length. The default value is 100 m.

### **Aggregate equivalent length of local resistances**

Represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. The default value is 50 m.

### **Tank minimum volume**

Minimum volume of fluid in the upstream tank, or in the pipe, corresponding to  $V_{\min}$  in the block equations. The tank or pipe is considered empty if its fluid volume becomes less than  $V_{\min}$ . The default value is 1e-4 m<sup>3</sup>.

### **Laminar flow upper margin**

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

### **Turbulent flow lower margin**

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

### **Internal surface roughness height**

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer catalogs. The default value is 5e-5 m.

## Vertical Position Tab

### Port A elevation wrt reference plane

The vertical position of the pipe port A with respect to the reference plane. The default value is 50 m.

### Port B elevation wrt reference plane

The vertical position of the pipe port B with respect to the reference plane. The default value is 0.

## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Pipe type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Pipe type** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

V

Physical signal input port that provides data on fluid volume in the upstream tank.

L

Physical signal output port that exports the pipe fluid level.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2013a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Hydraulic Pipe LP with Variable Elevation | Resistive Pipe LP with Variable Elevation

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Pilot-Operated Check Valve

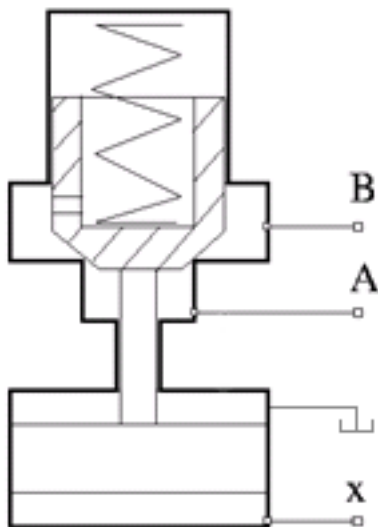
Hydraulic check valve that allows flow in one direction, but can be disabled by pilot pressure

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Directional Valves



### Description

The Pilot-Operated Check Valve block represents a hydraulic pilot-operated check valve as a data-sheet-based model. The purpose of the check valve is to permit flow in one direction and block it in the opposite direction, as shown in the following figure.



Unlike a conventional check valve, the pilot-operated check valve can be opened by inlet pressure  $p_A$ , pilot pressure  $p_X$ , or both. The force acting on the poppet is based on the expression

$$F = p_A \cdot A_A + p_X \cdot A_X - p_B \cdot A_B$$

where

$p_A, p_B$	Gauge pressures at the valve terminals
$p_X$	Pressure—gauge or differential—at the pilot terminal
$A_A$	Area of the spool in the A chamber
$A_B$	Area of the spool in the B chamber
$A_X$	Area of the pilot chamber

The force equation is commonly expressed in the slightly modified form

$$p_e = p_A + p_X \cdot k_p - p_B$$

where  $k_p = A_X / A_A$  is usually referred to as pilot ratio and  $p_e$  is the effective pressure differential across the control member. The valve remains closed while this pressure differential across the valve is lower than the valve cracking pressure. When cracking pressure is reached, the valve control member is forced off its seat, thus creating a passage between the inlet and outlet. If the flow rate is high enough and pressure continues to rise, the area is further increased until the control member reaches its maximum. At this moment, the valve passage area is at its maximum. The valve maximum area and the cracking and maximum pressures are generally provided in the catalogs and are the three key parameters of the block.

The pilot pressure can be a differential value relative to the inlet (port **A**) or a gauge value (relative to the environment). You can select an appropriate setting—**Pressure differential (pX - pA)** or **Pressure at port X**—using the **Pressure control specification** dropdown list. If **Pressure at port X** is selected:

$$p_X = p_{X,Abs} - p_{Atm}$$

where the subscript **Atm** denotes atmospheric pressure. The subscript **X, Abs** denotes the absolute value at the pilot port. If **Pressure differential (pX - pA)** is selected:

$$p_X = p_{X,Abs} - p_{A,Abs}$$

where the subscript **A, Abs** similarly denotes the absolute value at the inlet of the valve (port **A**). The pilot pressure differential is constrained to be greater than or equal to zero—if its calculated value should be negative, zero is assumed in the control pressure calculation.

In addition to the maximum area, the leakage area is also required to characterize the valve. The main purpose of the parameter is not to account for possible leakage, even though this is also important, but to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause failure of computation. Therefore, the parameter value must be greater than zero.

By default, the block does not include valve opening dynamics, and the valve sets its opening area directly as a function of pressure:

$$A = A(p)$$

Adding valve opening dynamics provides continuous behavior that is more physically realistic, and is particularly helpful in situations with rapid valve opening and closing. The pressure-dependent orifice passage area  $A(p)$  in the block equations then becomes the steady-state area, and the instantaneous orifice passage area in the flow equation is determined as follows:

$$A(t = 0) = A_{init}$$

$$\frac{dA}{dt} = \frac{A(p) - A}{\tau}$$

In either case, the flow rate through the valve is determined according to the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$p_e = p_A + p_X \cdot k_p - p_B$$



$$A(p) = \begin{cases} A_{leak} & \text{for } p_e \leq p_{crack} \\ A_{leak} + k \cdot (p_e - p_{crack}) & \text{for } p_{crack} < p_e < p_{max} \\ A_{max} & \text{for } p_e \geq p_{max} \end{cases}$$

$$k = \frac{A_{max} - A_{leak}}{p_{max} - p_{crack}}$$

$$\Delta p = p_A - p_B,$$

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$q$	Flow rate through the valve
$p$	Pressure differential across the valve
$p_e$	Equivalent pressure differential across the control member
$p_A, p_B$	Gauge pressures at the valve terminals
$p_X$	Gauge pressure at the pilot terminal
$k_p$	Pilot ratio, $k_p = A_X / A_A$
$k$	Valve gain coefficient
$C_D$	Flow discharge coefficient
$A$	Instantaneous orifice passage area
$A(p)$	Pressure-dependent orifice passage area
$A_{init}$	Initial open area of the valve
$A_{max}$	Fully open valve passage area
$A_{leak}$	Closed valve leakage area
$p_{crack}$	Valve cracking pressure
$p_{max}$	Pressure needed to fully open the valve
$p_{cr}$	Minimum pressure for turbulent flow
$Re_{cr}$	Critical Reynolds number
$D_H$	Instantaneous orifice hydraulic diameter
$\rho$	Fluid density
$\nu$	Fluid kinematic viscosity
$\tau$	Time constant for the first order response of the valve opening
$t$	Time

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as  $\Delta p = p_A - p_B$ .

## Assumptions and Limitations

- Valve opening is linearly proportional to the effective pressure differential.
- No loading on the valve, such as inertia, friction, spring, and so on, is considered.
- No flow consumption is associated with the pilot chamber.

## Ports

### Conserving

#### **A – Valve inlet**

hydraulic

Hydraulic conserving port associated with the valve inlet.

#### **B – Valve outlet**

hydraulic

Hydraulic conserving port associated with the valve outlet.

#### **X – Valve pilot terminal**

hydraulic

Hydraulic conserving port associated with the valve pilot terminal.

## Parameters

### **Pressure control specification – Choice of pressure measurement to use as pilot control signal**

Pressure differential ( $p_X - p_A$ ) (default) | Pressure at port X

Choice of pressure measurement to use as pilot control signal:

- Pressure differential ( $p_X - p_A$ ) — The effective pressure differential is a function of the pressure drop from the pilot port (**X**) to the inlet (**A**).
- Pressure at port X — The effective pressure differential is a function of the gauge pressure at the inlet.

The block uses the chosen measurement to calculate the effective pressure differential across the valve. See the block description for the calculations.

### **Cracking pressure – Pressure level at which the orifice of the valve starts to open**

$3e4$  Pa (default) | positive scalar

Pressure level at which the orifice of the valve starts to open.

### **Maximum opening pressure – Pressure differential across the valve needed to fully open the valve**

$1.2e5$  Pa (default) | positive scalar

Pressure differential across the valve needed to fully open the valve. Its value must be higher than the cracking pressure.

**Pilot ratio — Ratio between effective area in the pilot chamber to the effective area in the inlet chamber**

5 (default) | positive scalar

Ratio between effective area in the pilot chamber to the effective area in the inlet chamber.

**Maximum passage area — Valve passage maximum cross-sectional area**1e-4 m<sup>2</sup> (default) | positive scalar

Valve passage maximum cross-sectional area.

**Leakage area — Helps maintain numerical integrity of the circuit**1e-12 m<sup>2</sup> (default) | positive scalar

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0.

**Laminar transition specification — Select how block transitions between the laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar in the range of [0,1]

Pressure ratio at which the flow transitions between laminar and turbulent regimes.

**Dependencies**

This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

**Critical Reynolds number — Maximum Reynolds number for laminar flow**

12 (default) | positive scalar

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges.

**Dependencies**

This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

**Flow discharge coefficient — Semi-empirical parameter for valve capacity characterization**

0.7 (default) | positive scalar

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets.

**Opening dynamics — Specify whether to include valve opening dynamics in simulation**

Do not include valve opening dynamics (default) | Include valve opening dynamics

Select one of the following options:

- **Do not include valve opening dynamics** — The valve sets its orifice passage area directly as a function of pressure. If the area changes instantaneously, so does the flow equation.
- **Include valve opening dynamics** — Provide continuous behavior that is more physically realistic, by adding a first-order lag during valve opening and closing. Use this option in hydraulic simulations with the local solver for real-time simulation. This option is also helpful if you are interested in valve opening dynamics in variable step simulations.

**Opening time constant — Time constant for the first order response of the valve opening**

0.1 s (default) | positive scalar

The time constant for the first order response of the valve opening.

**Dependencies**

To enable this parameter, set **Opening dynamics** to Include valve opening dynamics.

**Initial area — Initial opening area of the valve**

1e-12 m<sup>2</sup> (default) | positive scalar

The initial opening area of the valve.

**Dependencies**

To enable this parameter, set **Opening dynamics** to Include valve opening dynamics.

## Version History

Introduced in R2006a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Check Valve

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Pilot-Operated Check Valve (IL)

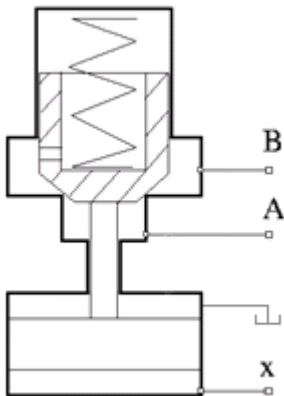
Check valve with pilot pressure control in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



### Description

The Pilot-Operated Check Valve (IL) block models a flow-control valve with variable flow directionality based on the pilot-line pressure. Flow is normally restricted to travel from port **A** to port **B** in either a connected or disconnected spool-poppet configuration, according to the **Pilot configuration** parameter.



### Pilot-Operated Check Valve Schematic

The control pressure,  $p_{\text{control}}$  is:

$$p_{\text{control}} = p_{\text{pilot}}k_p + (p_A - p_B),$$

where:

- $p_{\text{pilot}}$  is the control pilot pressure differential.
- $k_p$  is the **Pilot ratio**, the ratio of the area at port **X** to the area at port **A**:  $k_p = \frac{A_X}{A_A}$ .
- $p_A - p_B$  is the pressure differential over the valve.

When the control pressure exceeds the **Cracking pressure differential**, the poppet moves to allow flow from port **B** to port **A**.

There is no mass flow between port **X** and ports **A** and **B**.

### Valve Pressure Control with a Pilot Port

The pilot pressure differential for valve control can be configured in two ways:

- When the **Opening pilot pressure specification** parameter is set to Pressure at port X relative to port A, the pilot pressure is the pressure differential between port X and port A.
- When **Opening pilot pressure specification** is set to Pressure at port X relative to atmospheric pressure, the pilot pressure is the pressure difference between port X and atmospheric pressure.

When **Pilot configuration** is set to Disconnected pilot spool and poppet, the relative pressure at port X must be positive. If the measured pilot pressure is negative, the control pressure is only based on the pressure differential between ports A and B. In the Rigidly connected pilot spool and poppet setting, the pilot pressure is the measured pressure differential according to the opening specification.

### Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left(1 - \left(\frac{A_{valve}}{A_{port}}\right)^2\right) [\Delta p^2 + \Delta p_{crit}^2]^{1/4}}} \Delta p$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{valve}$  is the instantaneous valve open area.
- $A_{port}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference,  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** to Off. In this case,  $PR_{\text{loss}}$  is 1.

The opening area,  $A_{\text{valve}}$ , is also impacted by the valve opening dynamics.

### Opening Parameterization

The linear parameterization of the valve area is

$$A_{\text{valve}} = \hat{p}(A_{\text{max}} - A_{\text{leak}}) + A_{\text{leak}},$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{\text{control}} - p_{\text{cracking}}}{p_{\text{max}} - p_{\text{cracking}}}.$$

When the valve is in a near-open or near-closed position, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{\text{max}}$  and  $p_{\text{cracking}}$ . For more information, see “Numerical Smoothing”.

### Opening Dynamics

If opening dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{\text{control}}$  becomes the dynamic control pressure,  $p_{\text{dyn}}$ ; otherwise,  $p_{\text{control}}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{\text{dyn}} = \frac{p_{\text{control}} - p_{\text{dyn}}}{\tau}.$$

By default, **Opening dynamics** is set to Off.

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry point to the valve. When the control pressure exceeds the cracking pressure, liquid is able to exit from this port.

#### B — Liquid port

isothermal liquid

Liquid exit point from the valve. When the control pressure exceeds the cracking pressure, liquid is able to enter the valve from this port.

#### X — Pressure port

isothermal liquid

Pressure port that contributes to the flow control through the valve.

## Parameters

### **Pilot configuration — Valve geometry**

Rigidly connected pilot spool and poppet (default) | Disconnected pilot spool and poppet

Valve geometry. The valve can either have an opening mechanism that is connected to the valve poppet, in the case of the Rigidly connected pilot spool and poppet setting, or an opening mechanism that is aligned with, but moves freely away from, the valve poppet, in the case of the Disconnected pilot spool and poppet setting. The configuration choice determines the pilot pressure calculation.

### **Opening pilot pressure specification — Reference pressure differential for valve control**

Pressure at port X relative to port A (default) | Pressure at port X relative to atmospheric pressure

Reference pressure differential used for valve control. This differential defines the pilot pressure differential, which is added to the pressure differential between ports **A** and **B** and compared against the valve threshold **Cracking pressure differential**.

### **Cracking pressure differential — Pressure threshold**

0.01 MPa (default) | positive scalar

Set pressure for the valve operation.

### **Maximum opening pressure differential — Maximum pressure differential in opened valve**

0.02 MPa (default) | positive scalar

Maximum pressure differential in an opened valve. This value provides an upper limit to simulation pressures so that results remain physical.

### **Pilot ratio — Pilot port area ratio**

1 (default) | positive scalar in the range of (0,1]

Ratio of port area **X** to port area **A**.

### **Maximum opening area — Maximum valve area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum valve area. This value is used to determine the normalized valve pressure and the valve opening area during operation.

### **Leakage area — Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

### **Cross-sectional area at ports A and B — Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar



Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

#### **Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows.

#### **Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

#### **Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

#### **Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

#### **Opening dynamics — Whether to introduce flow lag due to valve opening**

Off (default) | On

Whether to account for transient effects to the fluid system due to opening the valve. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the pressure response. The **Opening time constant** also impacts the modeled opening dynamics.

#### **Opening time constant — Valve opening time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state conditions when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

#### **Dependencies**

To enable this parameter, set **Opening dynamics** to On.

## **Version History**

Introduced in R2020a

## **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Check Valve (IL) | Check Valve (TL) | Pressure Relief Valve (IL) | Counterbalance Valve (IL) | Pressure Compensator Valve (IL)

## Pilot-Operated Check Valve (TL)

Check valve with control port to enable flow in reverse direction

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Directional Control Valves



### Description

The Pilot-Operated Check Valve (TL) block models a check valve with an override mechanism to allow for backflow when activated. (A check valve in turn is an orifice with a unidirectional opening mechanism installed to prevent just that backflow.)

The override mechanism adds a third port—the *pilot*—to the valve. During normal operation, the pilot port is inactive and the valve behaves as any other check valve. Its orifice is then open only when the pressure gradient across it drops from inlet to outlet. Backflow, which requires the reverse pressure gradient, cannot occur. This mode protects components upstream of the valve against pressure surges, temperature spikes, and (in real systems) chemical contamination arising from points downstream.

When backflow is desired, the pilot port is pressurized and the control element of the valve—often a ball or piston—is forced off its seat. The valve is then open to flow in both directions, with a reverse pressure drop (aimed from outlet to inlet) sufficing to drive the flow upstream. (The seat, which lies in the path of the flow, determines if the valve is open. When it is covered—by a ball, piston, or other control element—the flow is cut off and the valve is closed.)

The valve opens by degrees, beginning at its cracking pressure, and continuing to the end of its pressure regulation range. The cracking pressure gives the initial resistance, due to friction or spring forces, that the valve must overcome to open by a sliver (or to *crack* open). Below this threshold, the valve is closed and only leakage flow can pass. Past the end of the pressure regulation range, the valve is fully open and the flow at a maximum (determined by the instantaneous pressure conditions).

The cracking pressure assumes an important role in check valves installed upside down. There, the weight of the opening element—such as a ball or piston—and the elevation head of the fluid can act to open the valve. (The elevation head can arise in a model from a pipe upstream of the inlet when it is vertical or given a slant.) A sufficient cracking pressure keeps the valve from opening inadvertently even if placed at a disadvantageous angle.

### Control Pressure

The opening of the valve depends both on the pilot pressure and on the pressure drop from inlet to outlet:

$$p_{\text{Ctl}} = k_X p_X + p_A - p_B,$$

where  $p$  is gauge pressure and  $k$  is the pilot ratio—the proportion of the pilot opening area ( $S_X$ ) to the valve opening area ( $S_R$ ). The subscript  $X$  denotes a pilot value and the subscripts  $A$  and  $B$  the inlet and outlet values, respectively. The port pressures are variables determined (against absolute zero) during simulation.

The pilot pressure can be a differential value relative to the inlet (port **A**) or a gauge value (relative to the environment). You can select an appropriate setting—**Pressure differential (pX - pA)** or **Pressure at port X**—using the **Pressure control specification** dropdown list. If **Pressure at port X** is selected:

$$p_X = p_{X,Abs} - p_{Atm},$$

where the subscript **Atm** denotes the atmospheric value (obtained from the Thermal Liquid Settings (TL) or Thermal Liquid Properties (TL) block of the model). The subscript **X, Abs** denotes the absolute value at the pilot port. If **Pressure differential (pX - pA)** is selected:

$$p_X = p_{X,Abs} - p_{A,Abs}$$

where the subscript **A, Abs** similarly denotes the absolute value at the inlet of the valve (port **A**). The pilot pressure differential is constrained to be greater than or equal to zero—if its calculated value should be negative, zero is assumed in the control pressure calculation.

### Control Pressure Overshoot

The degree to which the control pressure exceeds the cracking pressure determines how much the valve will open. The pressure overshoot is expressed here as a fraction of the (width of the) pressure regulation range:

$$\hat{p} = \frac{p_{Ctl} - P_{Crk}}{P_{Max} - P_{Crk}}.$$

The control pressure,  $p_{Ctl}$ , cracking pressure,  $p_{Crk}$ , and maximum opening pressure,  $P_{Max}$ , correspond to the control pressure specification chosen: **Pressure differential** or **Pressure at port A**.

The fraction—technically, the overshoot *normalized*—is valued at  $\theta$  in the fully closed valve and 1 in the fully open valve. If the calculation should return a value outside of these bounds, the nearest of the two is used instead. (In other words, the fraction *saturates* at  $\theta$  and 1.)

### Opening Parameterization

The linear parameterization of the valve area is

$$A_{valve} = \hat{p}(A_{max} - A_{leak}) + A_{leak},$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{cracking}}{p_{max} - p_{cracking}}.$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{cracking}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

### Opening Area

The valve area opens linearly with the smoothed control pressure,

$$S = (S_{Max} - S_{Min})\hat{p} + S_{Min},$$

where  $S_{Max}$  is the maximum valve area and  $S_{Min}$  is the value of the **Leakage area** parameter.

### Momentum Balance

The causes of those pressure losses incurred in the passages of the valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. This effect is captured in the block by the discharge coefficient, a measure of the mass flow rate through the valve relative to the theoretical value that it would have in an ideal valve. Expressing the momentum balance in the valve in terms of the pressure drop induced in the flow:

$$p_A - p_B = \frac{\dot{m}_{Avg} \sqrt{\dot{m}_{Avg}^2 + \dot{m}_{Crit}^2}}{2\rho_{Avg} C_D S^{*2}} \left[ 1 - \left( \frac{S^*}{S} \right)^2 \right] \xi_p,$$

where  $\rho$  is density,  $C_D$  is the discharge coefficient, and  $\xi_p$  is the pressure drop ratio—a measure of the extent to which the pressure recovery at the outlet contributes to the total pressure drop of the valve. The subscript Avg denotes an average of the values at the thermal liquid ports. The critical mass flow rate,  $\dot{m}_{Crit}$ , is calculated from the critical Reynolds number—that at which the flow in the valve is assumed to transition from laminar to turbulent:

$$\dot{m}_{Crit} = Re_{Crit} \mu_{Avg} \sqrt{\frac{\pi}{4} S},$$

where  $\mu$  denotes dynamic viscosity. The pressure drop ratio is calculated as:

$$\xi_p = \frac{\sqrt{1 - \left( \frac{S^*}{S} \right)^2 (1 - C_D^2)} - C_D \frac{S^*}{S}}{\sqrt{1 - \left( \frac{S^*}{S} \right)^2 (1 - C_D^2)} + C_D \frac{S^*}{S}}.$$

### Mass Balance

The volume of fluid inside the valve, and therefore the mass of the same, is assumed to be very small and it is, for modeling purposes, ignored. As a result, no amount of fluid can accumulate there. By the principle of conservation of mass, the mass flow rate into the valve through one port must therefore equal that out of the valve through the other port:

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate *into* the valve through port **A** or **B**.

### Energy Balance

The valve is modeled as an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. With these assumptions, energy can flow by advection only, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows must then always equal zero:

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is defined as the energy flow rate *into* the valve through one of the ports (**A** or **B**).

## Ports

### Conserving

#### **A – Valve entrance**

thermal liquid

Opening through which the working fluid must, during normal operation (when the pilot mechanism is disabled), enter the valve. This port can serve as an exit only when the pilot port is pressurized to a sufficient degree.

#### **B – Valve entrance**

thermal liquid

Opening through which the working fluid must, during normal operation (when the pilot mechanism is disabled), exit the valve.

#### **X – Pilot port**

thermal liquid

Opening by which to actuate (by the application of a sufficient pressure) the pilot mechanism that opens the valve for reverse flow.

## Parameters

### **Pressure control specification – Choice of pressure measurement to use as valve control signal**

Pressure differential (pX-pA) (default) | Pressure at port X

Choice of pressure measurement to use as pilot control signal. The block uses the chosen measurement to calculate the control pressure of the valve. (See the block description for the calculations.)

In the default setting (Pressure differential (pX - pA)), the control pressure is a function of the pressure drop from the pilot port (**X**) to the inlet (**A**). In the alternate setting (**Pressure at port X**), it is a function of the gauge pressure at the inlet.

### **Cracking pressure differential – Effective control pressure at which the valve first opens**

0.01 MPa (default) | positive scalar in units of pressure

Effective pressure differential at which the valve begins to open. This differential—the *control pressure* in the block description—is the sum of the pressure drop from inlet to outlet with the product of the pilot pressure and the pilot ratio. (The pilot pressure used depends on the setting of the **Pressure control specification** parameter.)

### **Maximum opening pressure differential – Effective control pressure at which the valve is fully open**

0.02 MPa (default) | positive scalar in units of pressure

Effective pressure differential at which the valve is fully open. This differential—the *control pressure* in the block description—is the sum of the pressure drop from inlet to outlet with the product of the pilot pressure and the pilot ratio. (The pilot pressure used depends on the setting of the **Pressure control specification** parameter.)

**Pilot ratio — Ratio of pilot port area to inlet port area**

1 (default) | positive unitless scalar

Ratio of the pilot port area to the inlet port area.

**Maximum opening area — Opening area in the fully open position due to sealing imperfections**1e-4 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully open position, when the valve is at the upper limit of the pressure regulation range.

**Leakage area — Opening area in the maximally closed position due to sealing imperfections**1e-10 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the maximally closed position, when only internal leakage between the ports remains. This parameter serves primarily to ensure that closure of the valve does not cause portions of the fluid network to become isolated (a condition known to cause problems in simulation). The exact value specified here is less important than its being a (very small) number greater than zero.

**Smoothing factor — Amount of smoothing to apply to the valve opening area function**

0 (default)

Amount of smoothing to apply to the opening area function of the valve. This parameter determines the widths of the regions to be smoothed—one located at the fully open position, the other at the fully closed position.

The smoothing superposes on each region of the opening area function a nonlinear segment (a third-order polynomial function, from which the smoothing arises). The greater the value specified here, the greater the smoothing is, and the broader the nonlinear segments become.

At the default value of 0, no smoothing is applied. The transitions to the maximally closed and fully open positions then introduce discontinuities (associated with zero-crossings), which tend to slow down the rate of simulation.

**Cross-sectional area at ports A and B — Area normal to the flow path at the valve ports**0.01 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the flow path at the valve ports. The ports are assumed to be the same in size. The flow area specified here should ideally match those of the inlets of adjoining components.

**Discharge coefficient — Empirical factor defined as the ratio of actual to ideal mass flow rates**

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

## **Version History**

**Introduced in R2018b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

2-Way Directional Valve (TL) | Orifice (TL) | 3-Way Directional Valve (TL) | Check Valve (TL)



# Pilot-Operated Check Valve (G)

Check valve with control port in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Directional Control Valves



## Description

The Pilot-Operated Check Valve (G) block represents a check valve with an override mechanism that allows backflow when activated. A check valve is an orifice with a unidirectional opening mechanism that prevents backflow.

The **X** port of the block represents a pilot port that serves as an override mechanism. During normal operation, the pilot port is inactive and the valve behaves as a check valve. In a check valve, the orifice only opens when the pressure gradient across the valve drops from inlet to outlet. The orifice opening prevents backflow, which requires the reverse pressure gradient, and protects the upstream components of the valve from downstream pressure surges, temperature spikes, and chemical contamination.

For sufficient values at port **X**, the block pressurizes the pilot port and forces the control element of the valve off its seat, permitting backflow. The valve is then open to flow in both directions, with a reverse pressure drop from outlet to inlet driving the flow upstream. The seat, which lies in the path of the flow, determines if the valve is open. When it is covered, the flow is cut off and the valve is closed.

The valve begins opening at the cracking pressure and continues opening until the end of the pressure regulation range. The cracking pressure is the initial resistance, due to friction or spring forces, that the valve must overcome to crack open. Below this threshold, the valve is closed and only leakage flow can pass. Past the end of the pressure regulation range, the valve is fully open and the flow at the maximum value is determined by the instantaneous pressure conditions.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

## Control and Other Pressures

The opening of the valve depends on the pilot pressure and the pressure drop from the inlet to the outlet. The pressure that opens the valve is

$$P_{Ctrl} = k_{pilot}P_{pilot} + P_A - P_B,$$

where:

- $P_{pilot}$  is the pilot pressure.

- $k_{pilot}$  is the pilot ratio.
- $P_A$  is the gauge pressure at port **A**.
- $P_B$  is the gauge pressure at port **B**.

The block determines the port pressures against absolute zero during simulation.

The pilot pressure can be relative to the inlet, port **A**, or relative to the environment. You can select the pilot pressure by setting the **Pilot pressure specification** parameter to Pressure difference of port X relative to port B or Gauge pressure at port X.

If you select Gauge pressure at port X, the pilot pressure is

$$P_{pilot} = P_X - P_{atm},$$

where  $P_{Atm}$  is the atmospheric pressure specified in the Gas Properties (G) block of the model and  $P_X$  is the absolute value of the pressure at the pilot port. If you select Pressure difference of port X relative to port A, the pilot pressure is

$$P_{pilot} = P_X - P_A,$$

where  $P_A$  is the absolute value of pressure at the inlet of the valve, port **A**.

When the **Pilot configuration** parameter is Rigidly connected pilot spool and poppet, the pilot spool transmits both positive and negative pilot forces and the block uses  $P_{pilot}$  as is in the equation for  $P_{Ctrl}$ . When the **Pilot configuration** parameter is Disconnected pilot spool and poppet, the pilot spool transmits only positive pilot pressure forces and  $P_{pilot}$  is limited to positive values. The block uses  $\max(P_{pilot}, 0)$  in the equation for  $P_{Ctrl}$ .

### Fraction of Valve Opening

The degree to which the control pressure exceeds the cracking pressure determines how much the valve opens. The fraction of valve opening is

$$\hat{p} = \frac{P_{Ctrl} - P_{Crk}}{P_{Max} - P_{Crk}},$$

where:

- $P_{Ctrl}$  is the control pressure.
- $P_{Crk}$  is the cracking pressure specified by the **Cracking pressure differential** parameter.
- $P_{Max}$  is the maximum opening pressure specified by the **Maximum opening pressure differential** parameter.

The fraction is normalized so that it is 0 in the fully closed valve and 1 in the fully open valve. If the calculation returns a value outside of these bounds, the block saturates the value to the nearest of the two limits.

### Numerical Smoothing

When the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized control pressure,  $\hat{p}$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

## Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parameterization.

The block scales the specified flow capacity by the fraction of valve opening. As the fraction of valve opening rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.

## Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3 p_{in} F_y x_T},$$

where:

- $F_y$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3F_{\gamma}x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma}x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3}C_v N_6 \sqrt{F_{\gamma}x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C\rho_{ref}p_{in}\sqrt{\frac{T_{ref}}{T_{in}}}\left[1 - \left(\frac{\frac{p_{out}}{p_{in}} - B_{crit}}{1 - B_{crit}}\right)^2\right]^m,$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C\rho_{ref}\sqrt{\frac{T_{ref}}{T_{avg}}}\left[1 - \left(\frac{B_{lam} - B_{crit}}{1 - B_{crit}}\right)^2\right]^m \left(\frac{p_{in} - p_{out}}{1 - B_{lam}}\right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C\rho_{ref}p_{in}\sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left(\frac{p_{out}}{p_{in}}\right)^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}}}\right]}$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \left[ \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}}\right] \left( \frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}\right)}$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Assumptions and Limitations

- The `Sonic conductance` setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the `Orifice area` parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

### Ports

#### Conserving

##### **A — Valve entrance**

gas

Gas conserving port associated with the opening through which the flow must enter the valve during normal operation when the pilot mechanism is disabled. This port can serve as an exit only when the pilot port is pressurized to a sufficient degree.

##### **B — Valve entrance**

gas

Gas conserving port associated with the opening through which the flow must exit the valve during normal operation when the pilot mechanism is disabled.

##### **X — Pilot port**

gas

Gas conserving port associated with the opening by which to actuate, by the application of a sufficient pressure, the pilot mechanism that opens the valve for reverse flow.

### Parameters

#### **Pilot configuration — Method for handling negative pilot pressure forces**

`Rigidly connected pilot spool and poppet (default)` | `Disconnected pilot spool and poppet`

Method the block uses when the pilot pressure is negative:

- `Rigidly connected pilot spool and poppet` — The pilot spool transmits both positive and negative pilot pressure forces, so the block uses  $p_{pilot}$  as is.
- `Disconnected pilot spool and poppet` — The pilot spool only transmits positive pilot pressure forces, so the block limits  $p_{pilot}$  to positive values only. The block replaces negative values with zero.

#### **Pilot pressure specification — Choice of pressure measurement to use as valve control signal**

`Pressure difference of port X relative to port A (default)` | `Gauge pressure at port X`

Choice of pressure measurement to use as valve control signal. The block uses this setting to determine when the valve should begin to open. In the default setting, **Pressure difference of port X relative to port A**, the opening pressure of the valve is expressed as a pressure drop from the pilot port, **X**, to the inlet, **A**. In the alternative setting, **Gauge pressure at port X**, it is expressed as a gauge inlet pressure measured against the environment pressure.

**Cracking pressure differential – Effective control pressure at which the valve first opens**

0.01 MPa (default) | positive scalar

Effective pressure differential at which the valve begins to open. This differential is the sum of the pressure drop from inlet to outlet with the product of the pilot pressure and the pilot ratio. The pilot pressure used depends on the setting of the **Pilot pressure specification** parameter.

**Maximum opening pressure differential – Effective control pressure at which the valve is fully open**

0.02 MPa (default) | positive scalar

Effective pressure differential at which the valve is fully open. This differential is the sum of the pressure drop from inlet to outlet with the product of the pilot pressure and the pilot ratio. The pilot pressure used depends on the setting of the **Pilot pressure specification** parameter.

**Pilot ratio – Ratio of pilot port area to inlet port area**

1 (default) | positive scalar

Ratio of the pilot port area to the inlet port area.

**Valve parameterization – Parameterization used to specify flow characteristics of orifice**

Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- **Cv flow coefficient** – The flow coefficient  $C_v$  determines the block parameterization.
- **Kv flow coefficient** – The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- **Sonic conductance** – The sonic conductance of the resistive element at steady state determines the block parameterization.
- **Orifice area** – The size of the flow restriction determines the block parametrization.

**Maximum Cv flow coefficient – Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Cv flow coefficient**.

**xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Maximum value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient.

**Maximum sonic conductance — Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar



Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**ISO reference density – ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**Maximum orifice area – Flow area corresponding to maximally open component**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Orifice area**.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Orifice area**.

**Leakage flow fraction – Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B – Flow area at gas ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

Introduced in R2018b

### Model gas systems using improved flow computations

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.
- **Pilot configuration**

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.
- The **Pressure control specification** parameter has been renamed to **Pilot pressure specification**. The options for this parameter have been renamed to **Pressure difference of port X relative to port A** and **Gauge pressure at port X**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power - Determination of flow-rate characteristics of components using compressible fluids - Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves - Part 2-3: Flow capacity - Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves - Part 2-1: Flow capacity - Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

Orifice (G) | Check Valve (G)

## Pilot Valve Actuator (IL)

Single-acting or double-acting actuator controlled by a pilot pressure in an isothermal liquid network

**Library:** Simscape / Fluids / Valve Actuators & Forces



### Description

The Pilot Valve Actuator (IL) block models a single-acting or double-acting actuator controlled by a pilot pressure for control of a connected valve or orifice in an isothermal liquid network.

For the single-acting actuator, when the control pressure,  $P_X - P_{atm}$ , exceeds the **Spring preload force at port X**, the piston begins to actuate in the direction assigned by the **Mechanical orientation** parameter.

For the double-acting actuator, the control pressure  $P_{control}$  is the difference between  $P_X - P_{atm}$  and  $P_Y - P_{atm}$ . The piston actuates in the direction of the larger applied pressure differential, opposing the spring force at the opposite port. When the piston motion reverses, this spring does not extend and does not exert a counterbalancing force on the piston position.

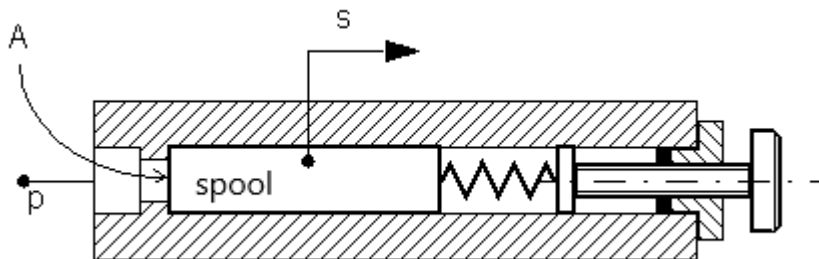
The pistons at port **X** and port **Y** are attached to a single spool. Both springs restore the spool to its neutral position when  $F_{spool}$  falls below the opposing spring preload force. For single-acting actuators, the neutral position is at port **X**. For double-acting actuators, the neutral position is at the center of the actuator.

### Single-Acting Actuator

The force on the piston is created by the pressure differential between port **X** and atmospheric pressure:

$$F_{spool} = (p_X - p_{atm})A_X,$$

where  $A_X$  is the **Piston area at port X**. When  $F_{spool}$  is greater than the **Spring preload force at port X**, the piston begins to move.



**Schematic of a Single-Acting Actuator**

### Piston Displacement

The instantaneous piston displacement is calculated as:

$$\dot{x}_{dyn} = \frac{x_{steady} - x_{dyn}}{\tau},$$

where the steady piston position,  $x_{steady}$ , is the piston position at the current pressure differential, proportional to the spring force at maximum piston stroke:

$$x_{steady} = F_{x_{stroke}} \varepsilon = \frac{F_{spool} - F_{pre}}{F_{max} - F_{pre}} x_{stroke} \varepsilon,$$

where:

- $F_{pre}$  is the **Spring preload force at port X**.
- $F_{max}$  is the maximum spring force acting against piston displacement,  $F_{max} = Kx_{stroke} + F_{pre}$ , and where  $K$  is the **Spring stiffness at port X**.
- $x_{stroke}$  is the **Piston stroke from port X**.
- $\varepsilon$  is the **Mechanical orientation**, which indicates piston movement in a positive direction (extension) or negative direction (retraction).

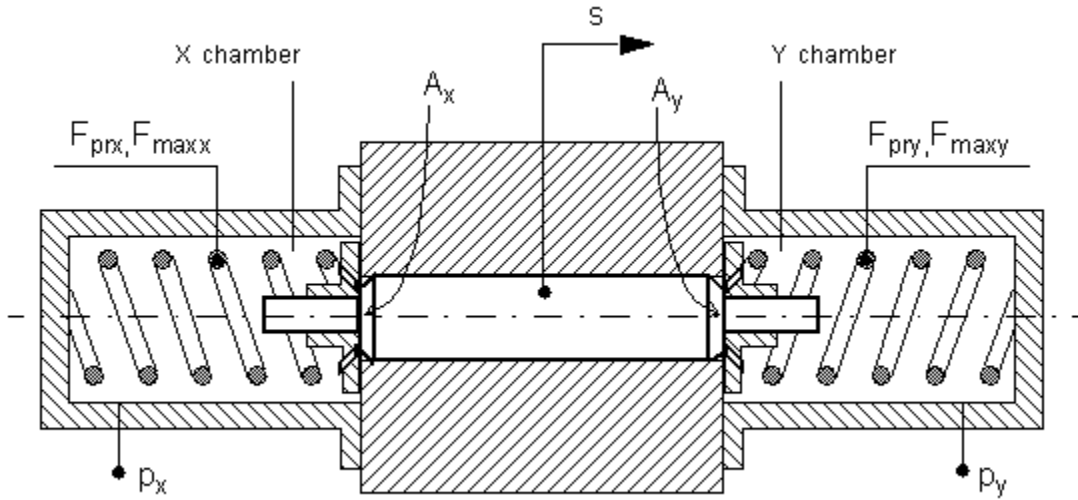
If the force on the piston is less than the **Spring preload force at X**, the piston remains at the neutral position or moves to the neutral position. If the force on the piston meets or exceeds the maximum spring force, the piston remains at the stroke until the applied pressure changes.

### Double-Acting Actuator

The difference between the forces at ports **X** and **Y** dictates the piston motion:

$$F_{spool} = (p_X - p_{atm})A_X - (p_Y - p_{atm})A_Y.$$

The pressure applied at port **X** shifts the spool away from the chamber at **X** and opposes the spring at port **Y**. Similarly, the pressure applied at port **Y** shifts the spool away from the chamber at **Y** and opposes the spring at port **X**. When the spool reverses direction, the formerly extended spring compresses, exerting a force on the spool. The formerly compressed spring, the spring at the port in the direction of motion, does not extend and does not influence the spool position.



### Schematic of a Double-Acting Actuator

#### Piston Displacement

The piston displacement is calculated as:

$$\dot{x}_{dyn} = \frac{x_{steady} - x_{dyn}}{\tau},$$

where the steady piston position,  $x_{steady}$ , is the piston position at the current pressure differential, proportional to the spring force at maximum piston stroke:

$$x_{steady} = (F_Y x_{stroke, Y} - F_X x_{stroke, X}) \varepsilon = \left( \frac{F_{spool} - F_{pre, Y}}{F_{max, Y} - F_{pre, Y}} x_{stroke, Y} - \frac{(-F_{spool} - F_{pre, X})}{F_{max, X} - F_{pre, X}} x_{stroke, X} \right) \varepsilon,$$

where:

- $F_{pre, X}$  and  $F_{pre, Y}$  are the **Spring preload force at port X** and **Spring preload force at port Y**, respectively.
- $F_{max, X}$  and  $F_{max, Y}$  are the maximum spring forces acting against piston displacement at ports **X** and **Y**, respectively, where:

$$F_{max} = K x_{stroke} + F_{pre},$$

$K$  is the spring stiffness per port.

- $x_{stroke}$  is the piston stroke per port.
- $\varepsilon$  is the **Mechanical orientation**, which assigns the signal for piston movement as positive (extension) or negative (retraction).

If the force on the piston is less than the respective port spring preload force, the piston remains or returns to the neutral position. If the force on the piston meets or exceeds the maximum spring force for the respective port, the piston remains at the piston stroke until the applied pressure changes.

## Numerically-Smoothed Force

When the actuator is close to full extension or full retraction, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. With a nonzero smoothing factor, a smoothing function is applied to all calculated forces, but primarily influences the simulation at the extremes of the piston motion.

When **Actuator configuration** is set to **Single-acting**, the normalized force on the piston is calculated as:

$$\widehat{F}_X = \frac{F_{spool} - F_{Pre}}{F_{max} - F_{Pre}}.$$

When **Actuator configuration** is set to **Double-acting**, the normalized force on the piston at **X** is calculated as:

$$\widehat{F}_X = \frac{-F_{spool} - F_{Pre,X}}{F_{max,X} - F_{Pre,X}}.$$

and the normalized force at **Y** is calculated as:

$$\widehat{F}_Y = \frac{F_{spool} - F_{Pre,Y}}{F_{max,Y} - F_{Pre,Y}}.$$

When the **Smoothing factor** is nonzero, the block smoothes each normalized force between 0 and 1.

For more information, see “Numerical Smoothing”.

## Ports

### Conserving

#### **X — Pressure port $P_X$**

isothermal liquid

Pressure at port **X**. There is no mass flow through the port.

#### **Y — Pressure port $P_Y$**

isothermal liquid

Pressure at port **Y**. There is no mass flow through the port.

### Dependencies

To enable this port, set **Actuator type** to **Double-acting**.

### Output

#### **S — Piston displacement, m**

physical signal

Piston displacement, specified as a physical signal. The displacement sign corresponds to the direction specified in the **Mechanical orientation** parameter.

## Parameters

### Actuator configuration — Type of actuator modeled

Single-acting (default) | Double-acting

Type of actuator modeled.

### Piston area at port X — Cross-sectional area of piston rod at port X

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod at port X.

### Piston area at port Y — Cross-sectional area of piston rod at port Y

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod at port Y.

### Dependencies

To enable this parameter, set **Actuator type** to Double-acting.

### Spring preload force — Force in the neutral position

20 N (default) | scalar

Force acting against the piston in the neutral position.

### Dependencies

To enable this parameter, set **Actuator type** to Single-acting.

### Spring preload force at port X — Force at port X in the neutral position

20 N (default) | scalar

Force at port X in the neutral position.

### Dependencies

To enable this parameter, set **Actuator type** to Double-acting.

### Spring preload force at port Y — Force at port Y in the neutral position

20 N (default) | scalar

Force at port Y in the neutral position.

### Dependencies

To enable this parameter, set **Actuator type** to Double-acting.

### Spring stiffness — Stiffness coefficient

15e3 N/m (default) | positive scalar

Spring stiffness factor. The maximum spring force is determined from the stiffness,  $K$ , and the **Spring preload force**:  $F_{\max} = Kx_{\text{stroke}} + F_{\text{pre}}$

### Dependencies

To enable this parameter, set **Actuator type** to Single-acting.



**Spring stiffness at port X — Stiffness coefficient at port X**

15e3 N/m (default) | positive scalar

Port **X** spring stiffness. The maximum spring force is determined from the stiffness,  $K$ , and the **Spring preload force at port X**:  $F_{\max} = Kx_{\text{stroke}} + F_{\text{pre}}$ .

**Dependencies**

To enable this parameter, set **Actuator type** to Double-acting.

**Spring stiffness at port Y — Stiffness coefficient at port Y**

15e3 N/m (default) | positive scalar

Port **Y** spring stiffness. The maximum spring force is determined from the stiffness,  $K$ , and the **Spring preload force at port Y**:  $F_{\max} = Kx_{\text{stroke}} + F_{\text{pre}}$ .

**Dependencies**

To enable this parameter, set **Actuator type** to Double-acting.

**Piston stroke — Maximum piston travel distance**

5e-3 m (default) | positive scalar

Maximum piston travel distance.

**Dependencies**

To enable this parameter, set **Actuator type** to Single-acting.

**Piston stroke from port X — Maximum piston travel distance at port X**

5e-3 m (default) | positive scalar

Maximum piston travel distance at port **X**.

**Dependencies**

To enable this parameter, set **Actuator type** to Double-acting.

**Piston stroke from port Y — Maximum piston travel distance at port Y**

5e-3 m (default) | positive scalar

Maximum piston travel distance at port **Y**.

**Dependencies**

To enable this parameter, set **Actuator type** to Double-acting.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Actuator dynamics — Whether to account for transients during actuation**

Off (default) | On

Whether to account for transient effects in the spool position due to actuation. Setting **Actuator dynamics** to On approximates actuator motion by introducing a first-order lag in the spool position. The **Actuator time constant** also impacts the modeled dynamics.

**Actuator time constant — Piston displacement time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the piston to reach steady-state when moving from one position to another. This parameter impacts the modeled actuator dynamics.

**Dependencies**

To enable this parameter, set **Actuator dynamics** to On.

**Mechanical orientation — Piston displacement direction**

Pilot pressure at port X causes positive piston displacement (default) | Pilot pressure at port X causes negative piston displacement

Sets the piston displacement direction based on the configuration at port **X**. If **Actuator configuration** is set to Double-acting, the displacement force at port **Y** acts in the opposite direction of the force at port **X**. Pilot pressure at port X causes positive piston displacement corresponds to positive displacement when the pressure at **X** pushes the piston towards port **Y**. Pilot pressure at port X causes negative piston displacement corresponds to negative displacement when the pressure at **X** pushes the piston towards port **Y**.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Single-Acting Actuator (IL) | Double-Acting Actuator (IL) | Pilot-Operated Check Valve (IL) | Cartridge Valve Actuator (IL)

# Pipe Bend

Hydraulic resistance in pipe bend



## Library

Local Hydraulic Resistances

### Description

The Pipe Bend block represents a pipe bend as a local hydraulic resistance. The pressure loss in the bend is assumed to consist of

- Loss in the straight pipe
- Loss due to curvature

The loss in a straight pipe is simulated with the Hydraulic Resistive Tube block. The loss due to curvature is simulated with the Local Resistance block, and the pressure loss coefficient is determined in accordance with the Crane Co. recommendations (see [1] on page 1-1329, p. A-29). The flow regime is checked in the underlying Local Resistance block by comparing the Reynolds number to the specified critical Reynolds number value.

The pressure loss due to curvature for turbulent flow regime is determined according to the following formula:

$$p = K \frac{\rho}{2A^2} q |q|$$

where

$q$	Flow rate
$p$	Pressure loss
$K$	Pressure loss coefficient
$A$	Bend cross-sectional area
$\rho$	Fluid density

For laminar flow regime, the formula for pressure loss computation is modified, as described in the reference documentation for the Local Resistance block.

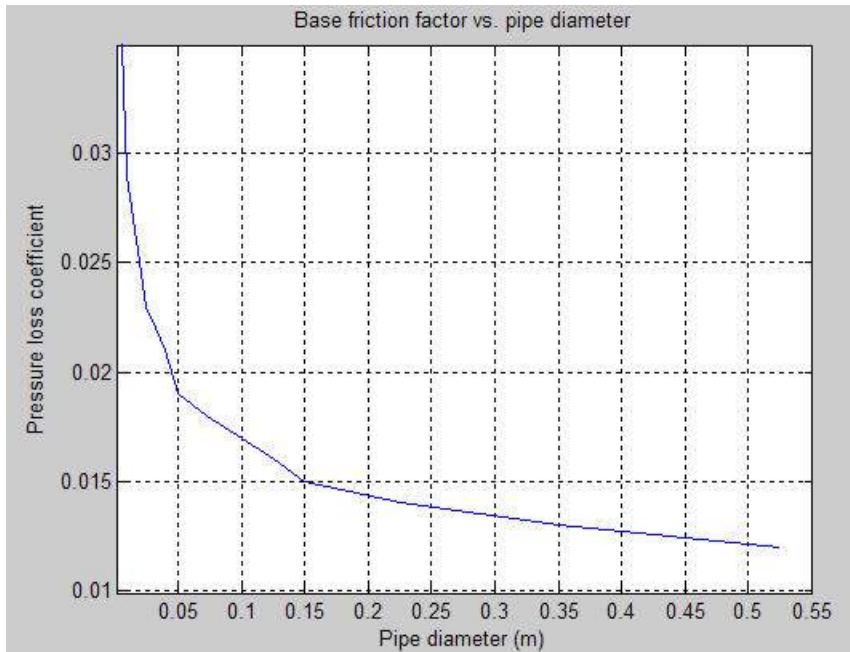
The pressure loss coefficient is determined according to recommendation provided in [1] on page 1-1329:

$$K = K_d \cdot K_r \cdot K_\alpha$$

where

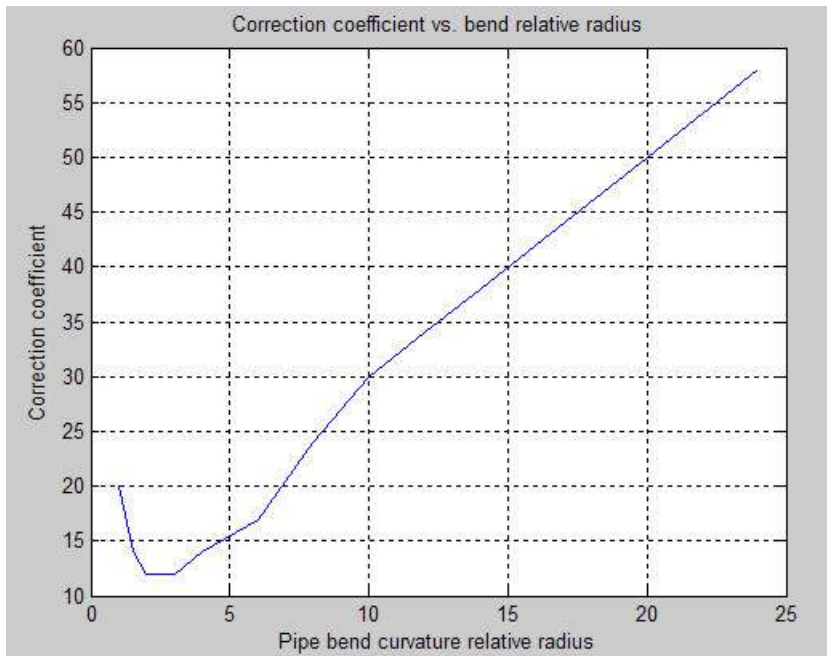
$K_d$	Base friction factor coefficient
$K_r$	Correction coefficient accounting for the bend curvature
$K_\alpha$	Correction coefficient accounting for the bend angle

The base friction factor coefficient is determined according to the following table.



**Note** Friction factors for pipes with diameters greater than 525 mm are determined by extrapolation.

The correction coefficient accounting for the bend curvature is determined according to the next table.



The bend curvature relative radius is calculated as

$$r = \text{bend radius} / \text{pipe diameter}$$

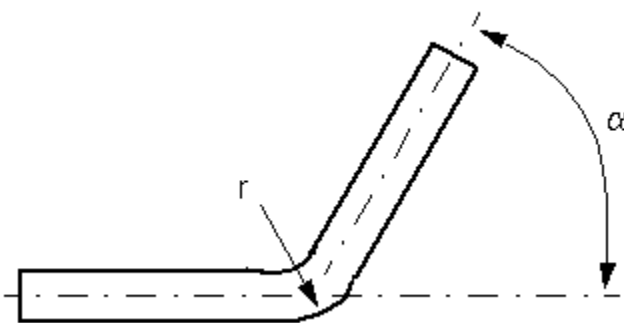
**Note** For pipes with the bend curvature relative radius value outside the range of  $1 > r > 24$ , correction coefficients are determined by extrapolation.

Correction for non-90° bends is performed with the empirical formula (see [2] on page 1-1329, Fig. 4.6):

$$K_{\alpha} = \alpha(0.0142 - 3.703 \cdot 10^{-5} \alpha)$$

where

$\alpha$	Bend angle in degrees ( $0 \leq \alpha \leq 180$ )
----------	--



Connections A and B are conserving hydraulic ports associated with the block inlet and outlet, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure differential is determined as  $p = p_A - p_B$ .

---

**Warning** The formulas used in the Pipe Bend block are very approximate, especially in the laminar and transient flow regions. For more accurate results, use a combination of the Local Resistance block with a table-specified  $K=f(Re)$  relationship and the Hydraulic Resistive Tube block.

---

## Basic Assumptions and Limitations

- Fluid inertia and wall compliance are not taken into account.
- The bend is assumed to be made of a clean commercial steel pipe.

## Parameters

### Pipe diameter

The internal diameter of the pipe. The default value is 0.01 m.

### Bend radius

The radius of the bend. The default value is 0.04 m.

### Bend angle

The angle of the bend. The value must be in the range between 0 and 180 degrees. The default value is 90 deg.

### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is 1.5e-5 m, which corresponds to drawn tubing.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 350.

### Fluid compressibility

Dynamic compressibility setting. Select **On** to make the fluid density dependent on pressure and temperature. Select **Off** to treat the fluid density as a constant. Dynamic compressibility impacts the transient response of the fluid at small time scales and can slow down simulation.

### Initial liquid pressure (gauge)

Gauge pressure in the pipe bend at time zero. The default value is 0 Pa.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the bend inlet.

B

Hydraulic conserving port associated with the bend outlet.

## References

[1] *Flow of Fluids Through Valves, Fittings, and Pipe*, Crane Valves North America, Technical Paper No. 410M

[2] George R. Keller, *Hydraulic System Analysis*, Published by the Editors of Hydraulics & Pneumatics Magazine, 1970

## Version History

Introduced in R2006b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Elbow | Gradual Area Change | Local Resistance | Hydraulic Resistive Tube | Sudden Area Change | T-junction

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Pipe Bend (IL)

Pipe bend segment in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Pipe Bend (IL) block models a curved pipe in an isothermal liquid network. You can define the pipe characteristics to calculate losses due to friction and pipe curvature and optionally model fluid compressibility.

#### Pipe Curvature Loss Coefficient

The coefficient for pressure losses due to geometry changes comprises an angle correction factor,  $C_{angle}$ , and a bend coefficient,  $C_{bend}$ :

$$K_{loss} = C_{angle}C_{bend}.$$

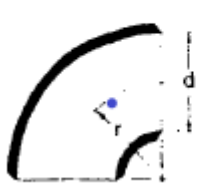
$C_{angle}$  is calculated as:

$$C_{angle} = 0.0148\theta - 3.9716 \cdot 10^{-5}\theta^2,$$

where  $\theta$  is the **Bend angle**, in degrees.

$C_{bend}$  is calculated from the tabulated ratio of bend radius to pipe diameter for 90° bends from Crane [1]:

**90° PIPE BENDS AND  
FLANGED OR BUTT-WELDING 90° ELBOWS**



$r/d$	$K$	$r/d$	$K$
1	$20 f_T$	8	$24 f_T$
1.5	$14 f_T$	10	$30 f_T$
2	$12 f_T$	12	$34 f_T$
3	$12 f_T$	14	$38 f_T$
4	$14 f_T$	16	$42 f_T$
6	$17 f_T$	20	$50 f_T$

The friction factor,  $f_T$ , for clean commercial steel is interpolated from tabular data based on pipe diameter [1]:



**PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE  
WITH FLOW IN ZONE OF COMPLETE TURBULENCE**

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_f$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

Note that the correction factor is valid for a ratio of bend radius to diameter between 1 and 24. Beyond this range, nearest-neighbor extrapolation is employed.

### Losses Due to Friction in Laminar Flows

The pressure loss formulations are the same for the flow at ports **A** and **B**.

When the flow in the pipe is fully laminar, or below  $Re = 2000$ , the pressure loss over the bend is:

$$\Delta p_{loss} = \frac{\mu \lambda}{2 \rho_I d^2 A} \frac{L}{2} \dot{m}_{port}$$

where:

- $\mu$  is the fluid dynamic viscosity.
- $\lambda$  is the Darcy friction factor constant, which is 64 for laminar flow.
- $\rho_I$  is the internal fluid density.
- $d$  is the pipe diameter.
- $L$  is the bend length segment, the product of the **Bend radius** and the **Bend angle**:  
 $L_{bend} = r_{bend} \theta$  ..
- $A$  is the pipe cross-sectional area,  $\frac{\pi}{4} d^2$ .
- $\dot{m}_{port}$  is the mass flow rate at the respective port.

### Losses due to Friction in Turbulent Flows

When the flow is fully turbulent, or greater than  $Re = 4000$ , the pressure loss in the pipe is:

$$\Delta p_{loss} = \left( \frac{f_D L}{2d} + \frac{K_{loss}}{2} \right) \frac{\dot{m}_{port} |\dot{m}_{port}|}{2 \rho_I A^2}$$

where  $f_D$  is the Darcy friction factor. This is approximated by the empirical Haaland equation and is based on the **Internal surface absolute roughness**. The differential is taken over half of the pipe segment, between port **A** to an internal node, and between the internal node and port **B**.

### Pressure Differential for Incompressible Fluids

When the flow is incompressible, the pressure loss over the bend is:

$$p_A - p_B = \Delta p_{loss, A} - \Delta p_{loss, B}$$

### Pressure Differential for Compressible Fluids

When the flow is compressible, the pressure loss over the bend is calculated based on the internal fluid volume pressure,  $p_I$ :

$$p_A - p_I = \Delta p_{loss, A}$$

$$p_B - p_I = \Delta p_{loss, B}$$

### Mass Conservation

For an incompressible fluid, the mass flow into the pipe equals the mass flow out of the pipe:

$$\dot{m}_A + \dot{m}_B = 0.$$

When the fluid is compressible, the difference between the mass flow into and out of the pipe depends on the fluid density change due to compressibility:

$$\dot{m}_A + \dot{m}_B = \dot{p}_I \frac{d\rho_I}{dp_I} V,$$

where  $V$  is the product of the pipe cross-sectional area and bend length,  $AL$ .

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Liquid entry or exit port.

#### B — Liquid port

isothermal liquid

Liquid entry or exit port.

## Parameters

### Pipe diameter — Pipe diameter

0.01 m (default) | positive scalar

Diameter of the pipe.

### Bend radius — Bend circle radius

0.04 m (default) | positive scalar

Radius of the circle formed by the pipe bend.

### Bend angle — Bend angle

90 deg (default) | positive scalar

Swept degree of the pipe bend.

**Internal surface absolute roughness — Pipe wall roughness**

15e-6 m (default) | positive scalar

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

**Fluid dynamic compressibility — Whether to model fluid compressibility**

Off (default) | On

Whether to model any change in fluid mass due to fluid compressibility. When **Fluid compressibility** is set to On, mass changes due to varying fluid density in the segment are calculated. The fluid volume in the pipe remains constant. In the Isothermal Liquid library, all blocks calculate density as a function of pressure.

**Initial liquid pressure — Pipe pressure at beginning of simulation**

0.101325 MPa (default) | positive scalar

Pipe pressure at the beginning of the simulation.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On.

## Version History

Introduced in R2020a

## References

[1] Crane Co. *Flow of Fluids Through Valves, Fittings, and Pipe TP-410*. Crane Co., 1981.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Elbow (IL) | T-Junction (IL) | Local Resistance (IL) | Area Change (IL) | Pipe (IL) | Partially Filled Pipe (IL)

## Pipe Bend (TL)

Pipe bend segment in a thermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Pipe Bend (TL) block models a curved pipe in a thermal liquid network. You can define the pipe characteristics to calculate losses due to friction and pipe curvature and optionally model fluid compressibility.

### Pipe Curvature Loss Coefficient

The coefficient for pressure losses due to geometry changes comprises an angle correction factor,  $C_{angle}$ , and a bend coefficient,  $C_{bend}$ :

$$K_{loss} = C_{angle}C_{bend}.$$

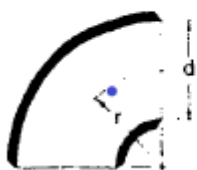
$C_{angle}$  is calculated as:

$$C_{angle} = 0.0148\theta - 3.9716 \cdot 10^{-5}\theta^2,$$

where  $\theta$  is the **Bend angle**, in degrees.

$C_{bend}$  is calculated from the tabulated ratio of bend radius to pipe diameter for 90° bends from Crane [1]:

**90° PIPE BENDS AND  
FLANGED OR BUTT-WELDING 90° ELBOWS**



$r/d$	$K$	$r/d$	$K$
1	$20 f_T$	8	$24 f_T$
1.5	$14 f_T$	10	$30 f_T$
2	$12 f_T$	12	$34 f_T$
3	$12 f_T$	14	$38 f_T$
4	$14 f_T$	16	$42 f_T$
6	$17 f_T$	20	$50 f_T$

The friction factor,  $f_T$ , for clean commercial steel is interpolated from tabular data based on pipe diameter [1]:

**PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE  
WITH FLOW IN ZONE OF COMPLETE TURBULENCE**

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_f$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

Note that the correction factor is valid for a ratio of bend radius to diameter between 1 and 24. Beyond this range, nearest-neighbor extrapolation is employed.

### Losses Due to Friction in Laminar Flows

The pressure loss formulations are the same for the flow at ports **A** and **B**.

When the flow in the pipe is fully laminar, or below  $Re = 2000$ , the pressure loss over the bend is:

$$\Delta p_{loss} = \frac{\mu \lambda}{2 \rho_I d^2 A} \frac{L}{2} \dot{m}_{port}$$

where:

- $\mu$  is the fluid dynamic viscosity.
- $\lambda$  is the Darcy friction factor constant, which is 64 for laminar flow.
- $\rho_I$  is the internal fluid density.
- $d$  is the pipe diameter.
- $L$  is the bend length segment, the product of the **Bend radius** and the **Bend angle**:  
 $L_{bend} = r_{bend} \theta$  ..
- $A$  is the pipe cross-sectional area,  $\frac{\pi}{4} d^2$ .
- $\dot{m}_{port}$  is the mass flow rate at the respective port.

### Losses due to Friction in Turbulent Flows

When the flow is fully turbulent, or greater than  $Re = 4000$ , the pressure loss in the pipe is:

$$\Delta p_{loss} = \left( \frac{f_D L}{2d} + \frac{K_{loss}}{2} \right) \frac{\dot{m}_{port} |\dot{m}_{port}|}{2 \rho_I A^2}$$

where  $f_D$  is the Darcy friction factor. This is approximated by the empirical Haaland equation and is based on the **Internal surface absolute roughness**. The differential is taken over half of the pipe segment, between port **A** to an internal node, and between the internal node and port **B**.

### Pressure Differential for Incompressible Fluids

When the flow is incompressible, the pressure loss over the bend is:

$$p_A - p_B = \Delta p_{loss, A} - \Delta p_{loss, B}$$

### Pressure Differential for Compressible Fluids

When the flow is compressible, the pressure loss over the bend is calculated based on the internal fluid volume pressure,  $p_I$ :

$$p_A - p_I = \Delta p_{loss, A},$$

$$p_B - p_I = \Delta p_{loss, B}.$$

### Mass Conservation

For an incompressible fluid, the mass flow into the pipe equals the mass flow out of the pipe:

$$\dot{m}_A + \dot{m}_B = 0.$$

For a flexible pipe with a compressible fluid, the pipe mass conservation equation is: This dependence is captured by the bulk modulus and thermal expansion coefficient of the thermal liquid:

$$\dot{m}_A + \dot{m}_B = \rho_I \dot{V} + \rho_I V \left( \frac{\dot{p}_I}{\beta_I} - \alpha_I \dot{T}_I \right),$$

where:

- $p_I$  is the thermal liquid pressure at the internal node I.
- $\dot{T}_I$  is the rate of change of the thermal liquid temperature at the internal node I.
- $\beta_I$  is the thermal liquid bulk modulus.
- $\alpha$  is the liquid thermal expansion coefficient.

### Energy Conservation

The energy conservation equation for the block is

$$V \frac{d(\rho u)}{dt} = \phi_A + \phi_B,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port associated with one end of the pipe bend.

#### B — Liquid port

thermal liquid

Thermal liquid conserving port associated with one end of the pipe bend.

## Parameters

### Pipe diameter — Pipe diameter

0.01 m (default) | positive scalar

Diameter of the pipe.

### Bend radius — Bend circle radius

0.04 m (default) | positive scalar

Radius of the circle formed by the pipe bend.

### Bend angle — Bend angle

90 deg (default) | positive scalar

Swept degree of the pipe bend.

### Internal surface absolute roughness — Pipe wall roughness

15e-6 m (default) | positive scalar

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

### Fluid dynamic compressibility — Whether to model fluid compressibility

Off (default) | On

Whether to model any change in fluid mass due to fluid compressibility. When **Fluid compressibility** is set to **On**, mass changes due to varying fluid density in the segment are calculated. The fluid volume in the pipe remains constant. In the Isothermal Liquid library, all blocks calculate density as a function of pressure.

### Initial liquid temperature — Liquid temperature at start of simulation

293.15 K (default)

Liquid temperature at the beginning of the simulation.

### Initial liquid pressure — Pipe pressure at beginning of simulation

0.101325 MPa (default) | positive scalar

Pipe pressure at the beginning of the simulation.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to **On**.

## Version History

Introduced in R2022a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## **See Also**



## Pipe (TL)

Closed conduit for the transport of fluid between thermal liquid components

**Library:** Simscape / Fluids / Thermal Liquid / Pipes & Fittings



### Description

The Pipe (TL) block represents thermal liquid flow through a pipe. The block finds the temperature across the pipe from the differential between ports, pipe elevation, and any additional heat transfer at port **H**.

The pipe can have a constant or varying elevation between ports **A** and **B**. For a constant elevation differential, use the **Elevation gain from port A to port B** parameter. You can specify a variable elevation by setting **Elevation gain specification** to Variable. This exposes physical signal port **EL**.

You can optionally include the effects of fluid dynamic compressibility, inertia, and wall flexibility. When the block includes these phenomena, it calculates the flow properties for each number of pipe segments that you specify.



### Pipe Flexibility

The block treats a flexible wall as a uniform radial expansion that maintains the original pipe cross-sectional shape. You can specify the pipe area in the **Nominal cross-sectional area** parameter, meaning that there is no specified cross-sectional geometry modeled by the block. However, the block uses the pipe hydraulic diameter in heat transfer and pressure loss calculations.

The deformation of the pipe diameter is calculated as:

$$\dot{D} = \frac{D_S - D}{\tau},$$

where:

- $D_S$  is the post-deformation, steady-state pipe diameter, and

$$D_S = D_N + K_c(p - p_{atm}),$$

where  $K_c$  is the **Static pressure-diameter compliance**,  $p$  is the tube pressure, and  $p_{atm}$  is the atmospheric pressure. Assuming elastic deformation of a thin-walled, open-ended pipe, you can calculate  $K_c$  as:

$$K_c = \frac{D^2}{2tE},$$

where  $t$  is the pipe wall thickness and  $E$  is Young's modulus.

- $D_N$  is the nominal pipe diameter, or the diameter previous to deformation:

$$D_N = \sqrt{\frac{4S}{\pi}},$$

where  $S$  is the value of the **Nominal cross-sectional area** parameter.

- $D$  is the **Hydraulic diameter** parameter.
- $\tau$  is the **Viscoelastic pressure time constant** parameter.

### Heat Transfer at the Pipe Wall

You can include heat transfer to and from the pipe walls in multiple ways. There are two analytical models: the Gnielinski correlation, which models the Nusselt number as a function of the Reynolds and Prandtl numbers with predefined coefficients, and the Dittus-Boelter correlation -  $Nusselt = a \cdot Re^b \cdot Pr^c$ , which models the Nusselt number as a function of the Reynolds and Prandtl numbers with user-defined coefficients.

The Nominal temperature differential vs. nominal mass flow rate, Tabulated data - Colburn factor vs. Reynolds number, and Tabulated data - Nusselt number vs. Reynolds number & Prandtl number are look-up table parameterizations based on user-supplied data.

Heat transfer between the fluid and pipe wall occurs through convection,  $Q_{Conv}$  and conduction,  $Q_{Cond}$ .

Heat transfer due to conduction is:

$$Q_{Cond} = \frac{k_I S_H}{D} (T_H - T_I),$$

where:

- $D$  is the **Hydraulic diameter** if the pipe walls are rigid, and is the pipe steady-state diameter,  $D_S$ , if the pipe walls are flexible.
- $k_I$  is the thermal conductivity of the thermal liquid, defined internally for each pipe segment.
- $S_H$  is the surface area of the pipe wall.
- $T_H$  is the pipe wall temperature.
- $T_I$  is the fluid temperature, taken at the pipe internal node.

Heat transfer due to convection is:

$$Q_{Conv} = c_{p,Avg} |\dot{m}_{Avg}| (T_H - T_{In}) \left[ 1 - \exp\left(-\frac{h S_H}{c_{p,Avg} |\dot{m}_{Avg}|}\right) \right],$$

where:

- $c_{p, Avg}$  is the average fluid specific heat.
- $\dot{m}_{Avg}$  is the average mass flow rate through the pipe.
- $T_{In}$  is the fluid inlet port temperature.
- $h$  is the pipe heat transfer coefficient.

The heat transfer coefficient  $h$  is:

$$h = \frac{Nu k_{Avg}}{D},$$

except when parameterizing by **Nominal temperature differential vs. nominal mass flow rate**, where  $k_{Avg}$  is the average thermal conductivity of the thermal liquid over the entire pipe and  $Nu$  is the average Nusselt number in the pipe.

### Analytical Parameterizations

When **Heat transfer parameterization** is set to **Gnielinski correlation** and the flow is turbulent, the average Nusselt number is calculated as:

$$Nu = \frac{f/8(Re-1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)},$$

where:

- $f$  is the average Darcy friction factor, according to the Haaland correlation:

$$f = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{Re} + \left( \frac{\epsilon_R}{3.7D} \right)^{1.11} \right] \right\}^{-2},$$

where  $\epsilon_R$  is the pipe **Internal surface absolute roughness**.

- $Re$  is the Reynolds number.
- $Pr$  is the Prandtl number.

When the flow is laminar, the Nusselt number is the **Nusselt number for laminar flow heat transfer** parameter.

When **Heat transfer parameterization** is set to **Dittus-Boelter correlation** and the flow is turbulent, the average Nusselt number is calculated as:

$$Nu = aRe^bPr^c,$$

where:

- $a$  is the value of the **Coefficient a** parameter.
- $b$  is the value of the **Exponent b** parameter.
- $c$  is the value of the **Exponent c** parameter.

The block default Dittus-Boelter correlation is:

$$Nu = 0.023Re^{0.8}Pr^{0.4}.$$

When the flow is laminar, the Nusselt number is the **Nusselt number for laminar flow heat transfer** parameter.

### Parameterization By Tabulated Data

When **Heat transfer parameterization** is set to Tabulated data - Colburn factor vs. Reynolds number, the average Nusselt number is calculated as:

$$\text{Nu} = J_M(\text{Re})\text{RePr}^{1/3}.$$

where  $J_M$  is the Colburn-Chilton factor.

When **Heat transfer parameterization** is set to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number, the Nusselt number is interpolated from the three-dimensional array of average Nusselt number as a function of both average Reynolds number and average Prandtl number:

$$\text{Nu} = \text{Nu}(\text{Re}, \text{Pr}).$$

When **Heat transfer parameterization** is set to Nominal temperature difference vs. nominal mass flow rate and the flow is turbulent, the heat transfer coefficient is calculated as:

$$h = \frac{h_N D_N^{1.8} \dot{m}_{\text{Avg}}^{0.8}}{\dot{m}_N^{0.8} D^{1.8}},$$

where:

- $\dot{m}_N$  is the **Nominal mass flow rate**.
- $\dot{m}_{\text{Avg}}$  is the average mass flow rate:

$$\dot{m}_{\text{Avg}} = \frac{\dot{m}_A - \dot{m}_B}{2}.$$

- $h_N$  is the nominal heat transfer coefficient, which is calculated as:

$$h_N = \frac{\dot{m}_N c_{p,N}}{S_{H,N}} \ln\left(\frac{T_{H,N} - T_{\text{In},N}}{T_{H,N} - T_{\text{Out},N}}\right),$$

where:

- $S_{H,N}$  is the nominal wall surface area.
- $T_{H,N}$  is the **Nominal wall temperature**.
- $T_{\text{In},N}$  is the **Nominal inflow temperature**.
- $T_{\text{Out},N}$  is the **Nominal outflow temperature**.

This relationship is based on the assumption that the Nusselt number is proportional to the Reynolds number:

$$\frac{hD}{k} \propto \left(\frac{\dot{m}D}{S\mu}\right)^{0.8}.$$

If the pipe walls are rigid, the expression for the heat transfer coefficient becomes:

$$h = \frac{h_N}{\dot{m}_N^{0.8}} \dot{m}_{\text{Avg}}^{0.8}.$$

## Pressure Loss Due to Friction

### Haaland Correlation

The analytical Haaland correlation models losses due to wall friction either by *aggregate equivalent length*, which accounts for resistances due to nonuniformities as an added straight-pipe length that results in equivalent losses, or by *local loss coefficient*, which directly applies a loss coefficient for pipe nonuniformities.

When the **Local resistances specification** parameter is set to **Aggregate equivalent length** and the flow in the pipe is lower than the **Laminar flow upper Reynolds number limit**, the pressure loss over all pipe segments is:

$$\Delta p_{f,A} = \frac{\nu \lambda}{2D^2 S} \frac{L + L_{add}}{2} \dot{m}_A,$$

$$\Delta p_{f,B} = \frac{\nu \lambda}{2D^2 S} \frac{L + L_{add}}{2} \dot{m}_B,$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $\lambda$  is the **Laminar friction constant for Darcy friction factor**, which you can define when **Cross-sectional geometry** is set to Custom and is otherwise equal to 64.
- $D$  is the pipe hydraulic diameter.
- $L_{add}$  is the **Aggregate equivalent length of local resistances**.
- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

When the Reynolds number is greater than the **Turbulent flow lower Reynolds number limit**, the pressure loss in the pipe is:

$$\Delta p_{f,A} = \frac{f}{2\rho_I S^2} \frac{L + L_{add}}{2} \dot{m}_A |\dot{m}_A|,$$

$$\Delta p_{f,B} = \frac{f}{2\rho_I S^2} \frac{L + L_{add}}{2} \dot{m}_B |\dot{m}_B|,$$

where:

- $f$  is the Darcy friction factor. This is approximated by the empirical Haaland equation and is based on the **Surface roughness specification**,  $\varepsilon$ , and pipe hydraulic diameter:

$$f = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}} + \left( \frac{\varepsilon}{3.7D_h} \right)^{1.11} \right] \right\}^{-2},$$

Pipe roughness for brass, lead, copper, plastic, steel, wrought iron, and galvanized steel or iron are provided as ASHRAE standard values. You can also supply your own **Internal surface absolute roughness** with the Custom setting.

- $\rho_I$  is the internal fluid density.

When the **Local resistances specification** parameter is set to **Local loss coefficient** and the flow in the pipe is lower than the **Laminar flow upper Reynolds number limit**, the pressure loss over all pipe segments is:

$$\Delta p_{f,A} = \frac{v\lambda}{2D^2S} \frac{L}{2} \dot{m}_A.$$

$$\Delta p_{f,B} = \frac{v\lambda}{2D^2S} \frac{L}{2} \dot{m}_B.$$

When the Reynolds number is greater than the **Turbulent flow lower Reynolds number limit**, the pressure loss in the pipe is:

$$\Delta p_{f,A} = \left( \frac{fL}{D} + C_{loss,total} \right) \frac{1}{2\rho IS^2} \dot{m}_A |\dot{m}_A|,$$

$$\Delta p_{f,B} = \left( \frac{fL}{D} + C_{loss,total} \right) \frac{1}{2\rho IS^2} \dot{m}_B |\dot{m}_B|,$$

where  $C_{loss,total}$  is the loss coefficient, which can be defined in the **Total local loss coefficient** parameter as either a single coefficient or the sum of all loss coefficients along the pipe.

#### Nominal Pressure Drop vs. Nominal Mass Flow Rate

The Nominal Pressure Drop vs. Nominal Mass Flow Rate parameterization characterizes losses with a loss coefficient for rigid or flexible walls. When the fluid is incompressible, the pressure loss over the entire pipe due to wall friction is:

$$\Delta p_{f,A} = K_p \dot{m}_A \sqrt{\dot{m}_A^2 + \dot{m}_{th}^2},$$

where  $K_p$  is:

$$K_p = \frac{\Delta p_N}{\dot{m}_N^2},$$

where:

- $\Delta p_N$  is the **Nominal pressure drop**, which can be defined either as a scalar or a vector.
- $\dot{m}_N$  is the **Nominal mass flow rate**, which can be defined either as a scalar or a vector.

When the **Nominal pressure drop** and **Nominal mass flow rate** parameters are supplied as vectors, the scalar value  $K_p$  is determined from a least-squares fit of the vector elements.

#### Tabulated Data - Darcy Friction Factor vs. Reynolds Number

Pressure losses due to viscous friction can also be determined from user-provided tabulated data of the **Darcy friction factor vector** and the **Reynolds number vector for turbulent Darcy friction factor** parameters. Linear interpolation is employed between data points.

#### Momentum Balance

The pressure differential over the pipe is due to the pressure at the pipe ports, friction at the pipe walls, and hydrostatic changes due to any change in elevation:

$$p_A - p_B = \Delta p_f + \rho_I g \Delta z,$$

where:

- $p_A$  is the pressure at a port **A**.
- $p_B$  is the pressure at a port **B**.
- $\Delta p_f$  is the pressure differential due to viscous friction,  $\Delta p_{f,A} + \Delta p_{f,B}$ .
- $g$  is **Gravitational acceleration**.
- $\Delta z$  the elevation differential between port **A** and port **B**, or  $z_A - z_B$ .
- $\rho_I$  is the internal fluid density, which is measured at each pipe segment. If fluid dynamic compressibility is not modeled, this is:

$$\rho_I = \frac{p_A + p_B}{2}.$$

When fluid inertia is not modeled, the momentum balance between port **A** and internal node I is:

$$p_A - p_I = \Delta p_{f,A} + \rho_I g \frac{\Delta z}{2}.$$

When fluid inertia is not modeled, the momentum balance between port **B** and internal node I is:

$$p_B - p_I = \Delta p_{f,B} - \rho_I g \frac{\Delta z}{2}.$$

When fluid inertia is modeled, the momentum balance between port **A** and internal node I is:

$$p_A - p_I = \Delta p_{f,A} + \rho_I g \frac{\Delta z}{2} + \frac{\ddot{m}_A L}{S} \frac{L}{2},$$

where:

- $\ddot{m}_A$  is the fluid inertia at port **A**.
- $L$  is the **Pipe length**.
- $S$  is the **Nominal cross-sectional area**.

When fluid inertia is modeled, the momentum balance between port **B** and internal node I is:

$$p_B - p_I = \Delta p_{f,B} - \rho_I g \frac{\Delta z}{2} + \frac{\ddot{m}_B L}{S} \frac{L}{2},$$

where

$\ddot{m}_B$  is the fluid inertia at port **B**.

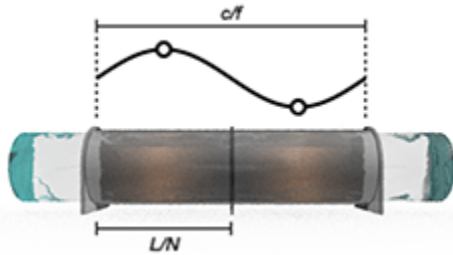
### Pipe Discretization

You can divide the pipe into multiple segments. If a pipe has more than one segment, the mass flow, energy flow, and momentum balance equations are calculated for each segment. Having multiple pipe segments can allow you to track changes to variables such as fluid density when fluid dynamic compressibility is modeled.

If you would like to capture specific phenomena in your application, such as water hammer, choose a number of segments that provides sufficient resolution of the transient. The following formula, from

the Nyquist sampling theorem, provides a rule of thumb for pipe discretization into a minimum of  $N$  segments:

$$N = 2L \frac{f}{c},$$



where:

- $L$  is the **Pipe length**.
- $f$  is the transient frequency.
- $c$  is the speed of sound.

For some applications, you may need to connect Pipe (TL) blocks in series. For example, you may require multiple pipe segments to define a thermal boundary condition along the length of a pipe. In this case, model the pipe segments by using a Pipe (TL) block for each segment and use the thermal ports to set the thermal boundary condition.

### Mass Balance

For a rigid pipe with an incompressible fluid, the pipe mass conservation equation is:

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

For a flexible pipe with an incompressible fluid, the pipe mass conservation equation is:

$$\dot{m}_A + \dot{m}_B = \rho_I \dot{V},$$

where:

- $\rho_I$  is the thermal liquid density at internal node I. Each pipe segment has an internal node.
- $\dot{V}$  is the rate of deformation of the pipe volume.

For a flexible pipe with a compressible fluid, the pipe mass conservation equation is: This dependence is captured by the bulk modulus and thermal expansion coefficient of the thermal liquid:

$$\dot{m}_A + \dot{m}_B = \rho_I \dot{V} + \rho_I V \left( \frac{\dot{p}_I}{\beta_I} + \alpha_I \dot{T}_I \right),$$



where:

- $p_I$  is the thermal liquid pressure at the internal node I.
- $\dot{T}_I$  is the rate of change of the thermal liquid temperature at the internal node I.
- $\beta_I$  is the thermal liquid bulk modulus.
- $\alpha$  is the liquid thermal expansion coefficient.

### Energy Balance

The energy accumulation rate in the pipe at internal node I is defined as:

$$\dot{E} = \phi_A + \phi_B + \phi_H - \dot{m}_{Avg}g\Delta z,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.
- $\phi_H$  is the energy flow rate at port **H**.

The total energy is defined as:

$$E = \rho_I u_I V,$$

where:

- $u_I$  is the fluid specific internal energy at node I.
- $V$  is the pipe volume.

If the fluid is compressible, the expression for energy accumulation rate is:

$$\dot{E} = \rho_I V \left( \frac{du}{dp} \frac{dp}{dt} + \frac{du}{dT} \frac{dT}{dt} \right)_I.$$

If the fluid is compressible and the pipe walls are flexible, the expression for energy accumulation rate is:

$$\dot{E} = \rho_I V \left( \frac{du}{dp} \frac{dp}{dt} + \frac{du}{dT} \frac{dT}{dt} \right)_I + (\rho_I u_I + p_I) \left( \frac{dV}{dt} \right)_I.$$

## Ports

### Input

#### EL — Port elevation difference

physical signal

Variable elevation differential between port **A** and **B**, specified as a physical signal.

### Conserving

#### A — Pipe opening

thermal liquid

Liquid entry or exit port to the pipe.

**B – Pipe opening**

thermal liquid

Liquid entry or exit port to the pipe.

**H – Pipe wall**

thermal

Pipe wall temperature.

## Parameters

### Configuration

**Fluid dynamic compressibility – Whether to model fluid dynamic compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure.

**Fluid inertia – Whether to model fluid acceleration**

On (default) | Off

Whether to account for acceleration in the mass flow rate due to the mass of the fluid.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

**Number of segments – Pipe discretization**

1 (default) | positive unitless scalar

Number of pipe divisions. Each division represents an individual segment over which pressure is calculated, depending on the pipe inlet pressure, fluid compressibility, and wall flexibility, if applicable. The fluid volume in each segment remains fixed.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

**Pipe total length – Total pipe length**

5 m (default) | positive scalar in units of length

Total pipe length across all pipe segments.

**Nominal cross-sectional area – Cross-sectional pipe area without deformation**

0.01 m<sup>2</sup> (default) | positive scalar in units of area

Cross-sectional area of the pipe without deformations.

**Pipe wall specification – Specifies wall flexibility**

Rigid (default) | Flexible

Specifies pipe walls as rigid or flexible. Flexible walls are modeled by a uniform radial expansion that maintains the original pipe cross-sectional shape.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

#### Hydraulic diameter — Effective diameter of noncircular pipes

0.1128 m (default) | positive scalar in units of length

Effective diameter used in heat transfer, momentum balance, and pipe flexibility equations. For noncircular pipes, the hydraulic diameter is the effective diameter of the fluid in the pipe. For circular pipes, the hydraulic diameter and pipe diameter are the same.

#### Dependencies

To enable this parameter, set either:

- **Fluid dynamic compressibility** to Off.
- **Pipe wall specification** to Rigid and **Fluid dynamic compressibility** to On.

#### Elevation gain specification — Set pipe elevation property

Constant (default) | Variable

Set the pipe elevation as either Constant or Variable. Selecting Variable exposes the physical signal port **EL**.

#### Elevation gain from port A to port B — Change in elevation from port A to port B

0 m (default) | positive scalar in units of length

Elevation differential for constant-elevation pipes. The elevation gain must be less than or equal to the **Pipe total length**.

#### Dependencies

To enable this parameter, set **Elevation gain specification** to Constant.

#### Gravitational acceleration — Acceleration due to gravity at mean pipe elevation

9.81 m/s<sup>2</sup> (default) | positive scalar in units of length/time<sup>2</sup>

Constant of the gravitational acceleration ( $g$ ) at the mean elevation of the pipe.

#### Static pressure-diameter compliance — Measure of pipe deformation

1.2e-6 m/MPa (default) | positive scalar in units of length/pressure

Coefficient of pipe radial deformation due to changes in pressure. This is a material property of the pipe.

#### Dependencies

To enable this parameter, set **Pipe wall specification** to Flexible.

#### Viscoelastic process time constant — Pipe deformation time constant

0.01 s (default) | positive scalar in units of time

Time required for the wall to reach steady-state after pipe deformation. This parameter impacts the dynamic change in pipe volume.

**Dependencies**

To enable this parameter, set **Pipe wall specification** to Flexible.

**Viscous Friction****Viscous friction parameterization – Friction model**

Haaland correlation (default) | Nominal pressure drop vs. nominal mass flow rate |  
Tabulated data - Darcy friction factor vs. Reynolds number

Parameterization of pressure losses due to wall friction. Both analytical and tabular formulations are available.

**Local resistances specification – Method for quantifying pressure losses in the Haaland correlation**

Aggregate equivalent length (default) | Local loss coefficient

Method for quantifying pressure losses due to pipe nonuniformities.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation.

**Total local loss coefficient – Defines loss coefficient over the pipe**

0.1 (default) | positive scalar

Loss coefficient associated with each pipe nonuniformity. You can input a single loss coefficient or the sum of all loss coefficients along the pipe.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation and **Local resistance specifications** to Local loss coefficient.

**Aggregate equivalent length of local resistances – Minor pressure loss in the pipe expressed as a length**

1 m (default) | positive scalar

Length of pipe that would produce the equivalent hydraulic losses as would a pipe with bends, area changes, or other nonuniformities. The effective length of the pipe is the sum of the **Pipe length** and the **Aggregate equivalent length of local resistances**.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation and **Local resistances specification** to Aggregate equivalent length.

**Internal surface absolute roughness – Pipe wall absolute roughness**

1.5e-5 m (default) | positive scalar in units of length

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation.

**Laminar friction constant for Darcy friction factor – Friction constant for laminar flows**

64 (default) | positive scalar

Friction constant for laminar flows. The Darcy friction factor captures the contribution of wall friction in pressure loss calculations.

**Laminar flow upper Reynolds number limit – Reynolds number below which the flow is laminar**

2e+3 (default) | positive scalar

Reynolds number below which the flow is laminar. Above this threshold, the flow transitions to turbulent, reaching the turbulent regime at the **Turbulent flow lower Reynolds number limit** setting.

**Turbulent flow lower Reynolds number limit – Reynolds number above which the flow is turbulent**

4e+3 (default) | positive scalar

Reynolds number above which the flow is turbulent. Below this threshold, the flow gradually transitions to laminar, reaching the laminar regime at the **Laminar flow upper Reynolds number limit** setting.

**Nominal mass flow rate – Pipe mass flow rate**

[0.1 1] kg/s (default) | scalar or vector of numbers in units of mass/time

Pipe nominal mass flow rate used to calculate the pressure loss coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal pressure drop** parameter. When this parameter is supplied as a vector, the scalar value  $K_p$  is determined as a least-squares fit of the vector elements.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

**Nominal pressure drop – Pressure drop over the pipe**

[0.001 0.01] MPa (default) | scalar or vector of numbers in units of pressure

Pipe nominal pressure drop used to calculate the pressure loss coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $K_p$  is determined as a least-squares fit of the vector elements.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

**Mass flow rate threshold for flow reversal – Threshold below which numerical smoothing is applied**

1e-6 kg/s (default) | positive scalar in units of mass/time

Mass flow rate threshold for reversed flow. A transition region is defined around 0 kg/s between the positive and negative values of the mass flow rate threshold. Within this transition region, numerical smoothing is applied to the flow response. The threshold value must be greater than 0.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

**Reynolds number vector for turbulent Darcy friction factor — Reynolds numbers at which to tabulate the Darcy friction factor**

[ 400 1000 1.5e+3 3e+3 4e+3 6e+3 1e+4 2e+4 4e+4 6e+4 1e+5 1e+8 ] (default) | vector of positive numbers

Vector of Reynolds numbers for the tabular parameterization of the Darcy friction factor. The vector elements form an independent axis with the **Darcy friction factor vector** parameter. The vector elements must be listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector — Darcy friction factors at the tabulated Reynolds numbers**

[ 0.264 0.112 0.07099999999999999 0.0417 0.0387 0.0268 0.025 0.0232 0.0226 0.022 0.0214 0.0214 ] (default) | vector of positive numbers

Vector of Darcy friction factors for the tabular parameterization of the Darcy friction factor. The vector elements must correspond one-to-one with the elements in the **Reynolds number vector for turbulent Darcy friction factor** parameter, and must be unique and greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

**Heat Transfer****Heat transfer parameterization — Method by which to capture the convective heat transfer with the pipe wall**

Gnielinski correlationNominal temperature differential vs. nominal mass flow rate (default) | Dittus-Boelter correlation | Tabulated data - Colburn factor vs. Reynolds number | Tabulated data - Nusselt number vs. Reynolds number & Prandtl number

Method of calculating the heat transfer coefficient between the fluid and the pipe wall. Analytical and tabulated data parameterizations are available.

**Nusselt number for laminar flow heat transfer — Nusselt number to use in the heat transfer calculations for laminar flows**

3.66 (default)

Ratio of convective to conductive heat transfer in the laminar flow regime. The fluid Nusselt number influences the heat transfer rate.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to either:

- Gnielinski correlation.
- Nominal temperature differential vs. nominal mass flow rate.
- Dittus-Boelter correlation.

#### **Nominal mass flow rate — Pipe mass flow rate**

[0.1 1] kg/s (default) | scalar or vector of numbers in units of mass/time

Pipe nominal mass flow rate used to calculate the heat transfer coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal inflow temperature** parameter. When this parameter is supplied as a vector, the scalar value  $h_p$  is determined as a least-squares fit of the vector elements.

#### **Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Nominal temperature differential vs. nominal mass flow rate.

#### **Nominal inflow temperature — Pipe inlet temperature**

[293.15 293.15] K (default) | scalar or vector of numbers in units of temperature

Nominal fluid inlet temperature used to calculate the heat transfer coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $h$  is determined as a least-squares fit of the vector elements.

#### **Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Nominal temperature differential vs. nominal mass flow rate.

#### **Nominal outflow temperature — Pipe outlet temperature**

[300 300] K (default) | scalar or vector of numbers in units of temperature

Nominal fluid outlet temperature used to calculate the heat transfer coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $h$  is determined as a least-squares fit of the vector elements.

#### **Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Nominal temperature differential vs. nominal mass flow rate.

#### **Nominal inflow pressure — Pipe inlet pressure**

[0.101325 0.101325] MPa (default) | scalar or vector of numbers in units of pressure

Nominal fluid inlet pressure used to calculate the heat transfer coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $h$  is determined as a least-squares fit of the vector elements.

#### **Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Nominal temperature differential vs. nominal mass flow rate.

**Nominal wall temperature — Pipe wall temperature**

[303.15 303.15] K (default) | scalar or vector of numbers in units of temperature

Pipe wall temperature used to calculate the heat transfer coefficient, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $h$  is determined as a least-squares fit of the vector elements.

**Dependencies**

To enable this temperature, set **Heat transfer parameterization** to Nominal temperature differential vs. nominal mass flow rate.

**Coefficient a — Empirical constant a of the Dittus-Boelter correlation**

0.023 (default) | positive scalar

Empirical constant  $a$  to use in the Dittus-Boelter correlation. The correlation relates the Nusselt number in turbulent flows to the heat transfer coefficient.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Dittus-Boelter correlation.

**Exponent b — Empirical constant b of the Dittus-Boelter correlation**

0.8 (default) | positive scalar

Empirical constant  $b$  to use in the Dittus-Boelter correlation. The correlation relates the Nusselt number in turbulent flows to the heat transfer coefficient.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Dittus-Boelter correlation.

**Exponent c — Empirical constant c of the Dittus-Boelter correlation**

0.4 (default) | positive scalar

Empirical constant  $c$  to use in the Dittus-Boelter correlation. The correlation relates the Nusselt number in turbulent flows to the heat transfer coefficient. The default value reflects heat transfer to the fluid.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Dittus-Boelter correlation.

**Reynolds number vector for Colburn factor — Reynolds numbers at which to tabulate the Colburn factor**

[100 150 1000] (default) | vector of positive numbers

Vector of Reynolds numbers for the tabular parameterization of the Colburn factor. The vector elements form an independent axis with the **Colburn factor vector** parameter. The vector elements must be listed in ascending order and must be greater than 0. This parameter must have the same number of elements as the **Colburn factor vector**. For reversed flows, or flows from **B** to **A**, the same data is applied in the opposite direction.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Colburn factor vs. Reynolds number.



**Colburn factor vector – Colburn factors at which the tabulated Reynolds numbers**

[0.019 0.013 0.002] (default) | vector of positive numbers

Vector of Colbrun factors for the tabular parameterization of the Colburn factor. The vector elements form an independent axis with the **Reynolds number vector for Colburn factor** parameter. This parameter must have the same number of elements as the **Reynolds number vector for Colburn factor**.

**Dependencies**

This parameter is active when the **Heat transfer parameterization** block parameter is set to Tabulated data - Colburn factor vs. Reynolds number.

**Reynolds number vector for Nusselt number – Reynolds number at which to tabulate the Nusselt number**

[100 150 100] (default) | vector of positive numbers

Vector of Reynolds numbers for the tabular parameterization of Nusselt number. This vector forms an independent axis with the **Prandtl number vector for Nusselt number** parameter for the 2-D dependent **Nusselt number table**. The vector elements must be listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Prandtl number vector for Nusselt number – Prandtl numbers at which to tabulate the Nusselt number**

[1 10] (default) | vector of positive numbers

Vector of Prandtl numbers for the tabular parameterization of Nusselt number. This vector forms an independent axis with the **Reynolds number vector for Nusselt number** parameter for the 2-D dependent **Nusselt number table**. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

**Nusselt number table – Nusselt numbers at the tabulated Reynolds and Prandtl numbers**

[ 3.72 4.21; 3.75 4.44; 4.21 7.15 ] (default) | matrix of positive numbers

$M$ -by- $N$  matrix of Nusselt numbers at the specified Reynolds and Prandtl numbers. Linear interpolation is employed between table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Reynolds number vector for Nusselt number** parameter.
- $N$  is the number of vector elements in the **Prandtl number vector for Nusselt number** parameter.

**Dependencies**

To enable this parameter, set **Heat transfer parameterization** to Tabulated data - Nusselt number vs. Reynolds number & Prandtl number.

## Initial Conditions

### **Initial liquid temperature — Absolute temperature in the pipe at the start of simulation**

293.15 K (default) | positive scalar or vector in units of temperature

Liquid temperature at the start of the simulation, specified as a scalar or vector. A vector  $n$  elements long defines the liquid temperature for each of  $n$  pipe segments. If the vector is two elements long, the temperature along the pipe is linearly distributed between the two element values. If the vector is three or more elements long, the initial temperature in the  $n$ th segment is set by the  $n$ th element of the vector.

### **Initial liquid pressure — Absolute pressure in the pipe at the start of simulation**

0.101325 MPa (default) | positive scalar or vector in units of pressure

Absolute liquid pressure at the start of the simulation, specified as a scalar or vector. A vector  $n$  elements long defines the liquid pressure for each of  $n$  pipe segments. If the vector is two elements long, the pressure along the pipe is linearly distributed between the two element values. If the vector is three or more elements long, the initial pressure in the  $n$ th segment is set by the  $n$ th element of the vector.

## Version History

**Introduced in R2016a**

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Sudden Area Change (TL) | Pipe (IL)

# Pipe (IL)

Pipe segment in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



## Description

The Pipe (IL) block models flow in a rigid or flexible-walled pipe with losses due to wall friction. The effects of dynamic compressibility, fluid inertia, and pipe elevation can be optionally modeled. You can define multiple pipe segments and set the liquid pressure for each segment. By segmenting the pipe and setting **Fluid inertia** to **On**, you can model events such as water hammer in your system.

### Pipe Characteristics

The pipe block can be divided into segments with the **Number of segments** parameter. When the pipe is composed of a number of segments, the pressure in each segment is calculated based on the inlet pressure and the effect on the segment mass flow rate of the fluid compressibility and wall flexibility, if applicable. The fluid volume in each segment remains fixed. For a two-segment pipe, the pressure evolves linearly with respect to the pressure defined at ports **A** and **B**. For a pipe with three or more segments, you can specify the fluid pressure in each segment in vector or scalar form in the **Initial liquid pressure** parameter. The scalar form will apply a constant value over all segments.

### Flexible Walls

You can model flexible walls for all cross-sectional geometries. When you set **Pipe wall specification** to **Flexible**, the block assumes uniform expansion along all directions and preserves the defined cross-sectional shape. This may not result in physical results for noncircular cross-sectional areas undergoing high pressure relative to atmospheric pressure. Two options are available for modeling the volumetric expansion of a cross-sectional area:

- 1 **Cross-sectional area vs. pressure**, where the change in volume is modeled by:

$$\dot{V} = L \left( \frac{S_N + K_{ps}(p - p_{atm}) - S}{\tau} \right),$$

where:

- $L$  is the **Pipe length**.
- $S_N$  is the nominal pipe cross-sectional area defined for each shape.
- $S$  is the current pipe cross-sectional area.
- $p$  is the internal pipe pressure.
- $p_{atm}$  is the atmospheric pressure.
- $K_{ps}$  is the **Static pressure-cross sectional area gain**.

Assuming uniform elastic deformation of a thin-walled, open-ended cylindrical pipe, you can calculate  $K_{ps}$  as:

$$K_{ps} = \frac{\Delta D}{\Delta p} = \frac{\pi D_N^3}{4tE},$$

where  $t$  is the pipe wall thickness and  $E$  is Young's modulus.

- $\tau$  is the **Volumetric expansion time constant**.

2 Hydraulic diameter vs. pressure, where the change in volume is modeled by:

$$\dot{V} = \frac{\pi}{2}DL \left( \frac{D_N + K_{pd}(p - p_{atm}) - D}{\tau} \right),$$

where:

- $D_N$  is the nominal hydraulic diameter defined for each shape.
- $D$  is the current pipe hydraulic diameter.
- $K_{pd}$  is the **Static pressure-hydraulic diameter gain**. Assuming uniform elastic deformation of a thin-walled, open-ended cylindrical pipe, you can calculate  $K_{pd}$  as:

$$K_{pd} = \frac{\Delta D}{\Delta p} = \frac{D_N^2}{2tE}.$$

When flexible walls are not modeled,  $S_N = S$  and  $D_N = D$ .

### Circular

The nominal hydraulic diameter and the **Pipe diameter**,  $d_{circle}$ , are the same. The pipe cross sectional area is:  $S_N = \frac{\pi}{4}d_{circle}^2$ .

### Annular

The nominal hydraulic diameter,  $D_{h,nom}$ , is the difference between the **Pipe outer diameter** and **Pipe inner diameter**,  $d_o - d_i$ . The pipe cross sectional area is  $S_N = \frac{\pi}{4}(d_o^2 - d_i^2)$ .

### Rectangular

The nominal hydraulic diameter is:

$$D_N = \frac{2hw}{h+w},$$

where:

- $h$  is the **Pipe height**.
- $w$  is the **Pipe width**.

The pipe cross sectional area is  $S_N = wh$ .

### Elliptical

The nominal hydraulic diameter is:

$$D_N = 2a_{maj}b_{min} \frac{\left( 64 - 16 \left( \frac{a_{maj} - b_{min}}{a_{maj} + b_{min}} \right)^2 \right)}{(a_{maj} + b_{min}) \left( 64 - 3 \left( \frac{a_{maj} - b_{min}}{a_{maj} + b_{min}} \right)^4 \right)},$$

where:

- $a_{\text{maj}}$  is the **Pipe major axis**.
- $b_{\text{min}}$  is the **Pipe minor axis**.

The pipe cross sectional area is  $S_N = \frac{\pi}{4} a_{\text{maj}} b_{\text{min}}$ .

### Isosceles Triangular

The nominal hydraulic diameter is:

$$D_N = l_{\text{side}} \frac{\sin(\theta)}{1 + \sin\left(\frac{\theta}{2}\right)}$$

where:

- $l_{\text{side}}$  is the **Pipe side length**.
- $\theta$  is the **Pipe vertex angle**.

The pipe cross sectional area is  $S_N = \frac{l_{\text{side}}^2}{2} \sin(\theta)$ .

### Pressure Loss Due to Friction

#### Haaland Correlation

The analytical Haaland correlation models losses due to wall friction either by *aggregate equivalent length*, which accounts for resistances due to nonuniformities as an added straight-pipe length that results in equivalent losses, or by *local loss coefficient*, which directly applies a loss coefficient for pipe nonuniformities.

When the **Local resistances specification** parameter is set to **Aggregate equivalent length** and the flow in the pipe is lower than the **Laminar flow upper Reynolds number limit**, the pressure loss over all pipe segments is:

$$\Delta p_{f,A} = \frac{\nu \lambda}{2D^2 S} \frac{L + L_{\text{add}}}{2} \dot{m}_A,$$

$$\Delta p_{f,B} = \frac{\nu \lambda}{2D^2 S} \frac{L + L_{\text{add}}}{2} \dot{m}_B,$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $\lambda$  is the **Laminar friction constant for Darcy friction factor**, which you can define when **Cross-sectional geometry** is set to Custom and is otherwise equal to 64.
- $D$  is the pipe hydraulic diameter.
- $L_{\text{add}}$  is the **Aggregate equivalent length of local resistances**.
- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

When the Reynolds number is greater than the **Turbulent flow lower Reynolds number limit**, the pressure loss in the pipe is:

$$\Delta p_{f,A} = \frac{f}{2\rho_I S^2} \frac{L + L_{add}}{2} \dot{m}_A |\dot{m}_A|,$$

$$\Delta p_{f,B} = \frac{f}{2\rho_I S^2} \frac{L + L_{add}}{2} \dot{m}_B |\dot{m}_B|,$$

where:

- $f$  is the Darcy friction factor. This is approximated by the empirical Haaland equation and is based on the **Surface roughness specification**,  $\varepsilon$ , and pipe hydraulic diameter:

$$f = \left\{ -1.8 \log_{10} \left[ \frac{6.9}{\text{Re}} + \left( \frac{\varepsilon}{3.7 D_h} \right)^{1.11} \right] \right\}^{-2},$$

Pipe roughness for brass, lead, copper, plastic, steel, wrought iron, and galvanized steel or iron are provided as ASHRAE standard values. You can also supply your own **Internal surface absolute roughness** with the Custom setting.

- $\rho_I$  is the internal fluid density.

When the **Local resistances specification** parameter is set to Local loss coefficient and the flow in the pipe is lower than the **Laminar flow upper Reynolds number limit**, the pressure loss over all pipe segments is:

$$\Delta p_{f,A} = \frac{v\lambda}{2D^2 S} \frac{L}{2} \dot{m}_A.$$

$$\Delta p_{f,B} = \frac{v\lambda}{2D^2 S} \frac{L}{2} \dot{m}_B.$$

When the Reynolds number is greater than the **Turbulent flow lower Reynolds number limit**, the pressure loss in the pipe is:

$$\Delta p_{f,A} = \left( \frac{fL}{D} + C_{loss,total} \right) \frac{1}{2\rho_I S^2} \dot{m}_A |\dot{m}_A|,$$

$$\Delta p_{f,B} = \left( \frac{fL}{D} + C_{loss,total} \right) \frac{1}{2\rho_I S^2} \dot{m}_B |\dot{m}_B|,$$

where  $C_{loss,total}$  is the loss coefficient, which can be defined in the **Total local loss coefficient** parameter as either a single coefficient or the sum of all loss coefficients along the pipe.

#### Nominal Pressure Drop vs. Nominal Mass Flow Rate

The Nominal Pressure Drop vs. Nominal Mass Flow Rate parameterization characterizes losses with a loss coefficient for rigid or flexible walls. When the fluid is incompressible, the pressure loss over the entire pipe due to wall friction is:

$$\Delta p_{f,A} = K_p \dot{m}_A \sqrt{\dot{m}_A^2 + \dot{m}_{th}^2},$$

where  $K_p$  is:

$$K_p = \frac{\Delta p_N}{\dot{m}_N^2},$$

where:

- $\Delta p_N$  is the **Nominal pressure drop**, which can be defined either as a scalar or a vector.
- $\dot{m}_N$  is the **Nominal mass flow rate**, which can be defined either as a scalar or a vector.

When the **Nominal pressure drop** and **Nominal mass flow rate** parameters are supplied as vectors, the scalar value  $K_p$  is determined from a least-squares fit of the vector elements.

#### Tabulated Data - Darcy Friction Factor vs. Reynolds Number

Pressure losses due to viscous friction can also be determined from user-provided tabulated data of the **Darcy friction factor vector** and the **Reynolds number vector for turbulent Darcy friction factor** parameters. Linear interpolation is employed between data points.

#### Momentum Balance

For an incompressible fluid, the mass flow into the pipe equals the mass flow out of the pipe:

$$\dot{m}_A + \dot{m}_B = 0.$$

When the fluid is compressible and pipe walls are rigid, the difference between the mass flow into and out of the pipe depends on the fluid density change due to compressibility:

$$\dot{m}_A + \dot{m}_B = \dot{\rho}_I \frac{d\rho_I}{dp_I} V,$$

When the fluid is compressible and the pipe walls are flexible, the difference between the mass flow into and out of the pipe is based on the change in fluid density due to compressibility, and the amount of fluid accumulated in the newly deformed regions of the pipe:

$$\dot{m}_A + \dot{m}_B = \dot{\rho}_I \frac{d\rho_I}{dp_I} V + \rho_I \dot{V}.$$

The changes in momentum between the pipe inlet and outlet comprises the changes in pressure due to pipe wall friction, which is modeled according to the **Viscous friction parameterization** and pipe elevation. For a pipe that does not model fluid inertia, the momentum balance is:

$$p_A - p_I = \Delta p_{f,A} + \rho_I \frac{\Delta z}{2} g,$$

$$p_B - p_I = \Delta p_{f,B} - \rho_I \frac{\Delta z}{2} g,$$

where:

- $p_A$  is the pressure at port **A**.
- $p_I$  is the fluid volume internal pressure.
- $p_B$  is the pressure at port **B**.
- $\Delta p_f$  is the pressure loss due to wall friction, parameterized by the **Viscous friction losses** specification according to the respective port.

- $\Delta z$  is the pipe elevation. In the case of constant-elevation pipes, this is the **Elevation gain from port A to port B** parameter; otherwise, it is received as a physical signal at port **EL**.
- $g$  is the gravitational acceleration. In the case of a fixed gravitational constant, this is the **Gravitational acceleration** parameter; otherwise, it is received as a physical signal at port **G**.

For a pipe with modeled fluid inertia, the momentum balance is:

$$p_A - p_I = \Delta p_{f,A} + \rho_I \frac{\Delta z}{2} g + \ddot{m}_A \frac{L}{2S},$$

$$p_B - p_I = \Delta p_{f,B} - \rho_I \frac{\Delta z}{2} g + \ddot{m}_B \frac{L}{2S},$$

where:

- $\ddot{m}$  is the fluid acceleration at its respective port.
- $S$  is the pipe cross-sectional area.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port.

### Inputs

#### EL – Elevation

physical signal

Variable elevation from port **A** to port **B**, specified as a physical signal. The elevation magnitude must be less than or equal to the pipe length. If the signal falls below the value of **-Pipe length**, the value at **EL** is maintained at **-pipe length**. If the signal exceeds the value of **Pipe length**, the value at **EL** is maintained at **pipe length**.

#### Dependencies

To enable this port, set **Elevation gain specification** to Variable.

#### G – Gravitational acceleration

physical signal

Variable gravitational acceleration, specified as a physical signal.

#### Dependencies

To enable this port, set **Gravitational acceleration specification** to Variable.



## Parameters

### Configuration

#### Pipe length — Pipe length

5 m (default) | positive scalar

Total pipe length across all pipe segments.

#### Number of segments — Number of pipe divisions

1 (default) | positive integer

Number of pipe divisions. Each division represents an individual segment for which pressure is calculated, depending on the pipe inlet pressure, fluid compressibility, and wall flexibility, if applicable. The fluid volume in each segment remains fixed.

#### Cross-sectional geometry — Pipe geometry

Circular (default) | Annular | Rectangular | Elliptical | Isosceles triangular | Custom

Cross-sectional pipe geometry. A nominal hydraulic diameter and nominal cross-sectional area is calculated based on the cross-sectional geometry.

#### Pipe diameter — Pipe diameter

0.1 m (default) | positive scalar

Diameter for circular cross-sectional pipes.

#### Dependencies

To enable this parameter, set **Cross-sectional geometry** to Circular.

#### Pipe inner diameter — Pipe inner diameter

0.05 m (default) | positive scalar

Inner diameter for annular pipe flow, or flow between two concentric pipes.

#### Dependencies

To enable this parameter, set **Cross-sectional geometry** to Annular.

#### Pipe outer diameter — Pipe outer diameter

0.1 m (default) | positive scalar

Outer diameter for annular pipe flow, or flow between two concentric pipes.

#### Dependencies

To enable this parameter, set **Cross-sectional geometry** to Annular.

#### Pipe width — Rectangular pipe width

0.1 m (default) | positive scalar

Width of rectangular pipe.

#### Dependencies

To enable this parameter, set **Cross-sectional geometry** to Rectangular.

**Pipe height — Rectangular pipe height**

0.1 m (default) | positive scalar

Height of rectangular pipe.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Rectangular.

**Pipe major axis — Ellipsoidal pipe major axis**

0.1 m (default) | positive scalar

Major axis for ellipsoidal pipes.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Elliptical.

**Pipe minor axis — Ellipsoidal pipe minor axis**

0.05 m (default) | positive scalar

Minor axis for ellipsoidal pipes.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Elliptical.

**Pipe side length — Triangular pipe side length**

0.1 m (default) | positive scalar

Length of the two equal sides of isosceles-triangular pipes.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Isosceles triangular.

**Pipe vertex angle — Triangular pipe vertex angle**

30 deg (default) | positive scalar

Vertex angle for triangular pipes. The value must be less than 180 degrees.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Isosceles triangular.

**Hydraulic diameter — Hydraulic diameter**

0.1128 m (default) | positive scalar

Hydraulic diameter used in calculations of the pipe Reynolds number. For noncircular pipes, the hydraulic diameter is the effective diameter of the fluid in the pipe. For circular pipes, the hydraulic diameter and pipe diameter are the same.

**Dependencies**

To enable this parameter, set **Cross-sectional geometry** to Custom.

**Cross-sectional area — Pipe cross-sectional area**

0.01 m<sup>2</sup> (default) | positive scalar

Pipe cross-sectional area for a custom pipe geometry.

#### Dependencies

To enable this parameter, set **Cross-sectional geometry** to Custom.

#### Fluid dynamic compressibility – Whether to model fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

#### Fluid inertia – Fluid acceleration

Off (default) | On

Whether to account for resistance to changes in the flow rate due to the fluid mass.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

#### Elevation gain specification – Pipe elevation specification

Constant (default) | Variable

Whether the pipe elevation remains constant or variable from port **A** to **B**.

#### Elevation gain from port A to port B – Constant pipe elevation differential

0 m (default) | scalar

Elevation differential for constant-elevation pipes. The elevation gain must be less than or equal to the **Pipe length**.

#### Dependencies

To enable this parameter, set **Elevation gain specification** to Constant.

#### Gravitational acceleration specification – Acceleration specification

Constant (default) | Variable

Whether the gravitational constant is constant or variable.

#### Gravitational acceleration – Gravitational acceleration

9.81 m/s<sup>2</sup> (default) | positive scalar

Gravitational acceleration for environments with constant gravitational acceleration.

#### Dependencies

To enable this parameter, set **Gravitational acceleration specification** to Constant.

#### Viscous Friction

#### Viscous friction parameterization – Method of calculating pressure loss due to wall friction

Haaland correlation (default) | Nominal pressure drop vs. nominal mass flow rate |  
Tabulated data - Darcy friction factor vs. Reynolds number

Parameterization of pressure losses due to wall friction. Both analytical and tabular formulations are available.

### **Local resistances specification – Method for quantifying pressure losses in the Haaland correlation**

Aggregate equivalent length (default) | Local loss coefficient

Method for quantifying pressure losses due to pipe nonuniformities.

#### **Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation.

### **Total local loss coefficient – Defines loss coefficient over the pipe**

0.1 (default) | positive scalar

Loss coefficient associated with each pipe nonuniformity. You can input a single loss coefficient or the sum of all loss coefficients along the pipe.

#### **Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation and **Local resistance specifications** to Local loss coefficient.

### **Aggregate equivalent length of local resistances – Contribution of pipe geometry to hydraulic losses**

1 m (default) | positive scalar

Length of pipe that would produce the equivalent hydraulic losses as would a pipe with bends, area changes, or other nonuniform attributes. The effective length of the pipe is the sum of the **Pipe length** and the **Aggregate equivalent length of local resistances**.

#### **Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation and **Local resistance specifications** to Aggregate equivalent length.

### **Surface roughness specification – Pipe material for roughness specification**

Commercially smooth brass, lead, copper, or plastic pipe: 1.52 um (default) | Steel and wrought iron : 46 um | Galvanized iron or steel : 152 um | Cast iron : 259 um | Custom

Absolute surface roughness based on pipe material. The provided values are ASHRAE standard roughness values. You can also input your own value by setting **Surface roughness specification** to Custom.

#### **Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation.

### **Internal surface absolute roughness – Pipe wall roughness**

15e-6 m (default) | positive scalar

Pipe wall absolute roughness. This parameter is used to determine the Darcy friction factor, which contributes to pressure loss in the pipe.

### Dependencies

To enable this parameter, set **Viscous friction parameterization** to Haaland correlation and **Surface roughness specification** to Custom.

### Laminar flow upper Reynolds number limit — Laminar flow upper threshold

2000 (default) | positive scalar

Upper Reynolds number limit to laminar flow. Beyond this number, the fluid regime is transitional, approaches the turbulent regime, and becomes fully turbulent at the **Turbulent flow lower Reynolds number limit**.

### Dependencies

To enable this parameter, set **Viscous friction parameterization** to either:

- Haaland correlation
- Tabulated data - Darcy friction factor vs. Reynolds number

### Turbulent flow lower Reynolds number limit — Turbulent flow lower threshold

4000 (default) | positive scalar

Lower Reynolds number limit for turbulent flow. Below this number, the flow regime is transitional, approaches laminar flow, and becomes fully laminar at the **Laminar flow upper Reynolds number limit**.

### Dependencies

To enable this parameter, set **Viscous friction parameterization** to either:

- Haaland correlation
- Tabulated data - Darcy friction factor vs. Reynolds number

### Nominal mass flow rate — Mass flow rate for calculating loss coefficient

[.1, 1] kg/s (default) | positive scalar | 1-by-*n* vector

Nominal mass flow rate used for calculating the pressure loss coefficient for rigid and flexible pipes, specified as a scalar or a vector. All nominal values must be greater than 0 and have the same number of elements as the **Nominal pressure drop** parameter. When this parameter is supplied as a vector, the scalar value  $K_{loss}$  is determined as a least-squares fit of the vector elements.

### Dependencies

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

### Nominal pressure drop — Pressure drop for calculating loss coefficient

[.001, .01] MPa (default) | positive scalar | 1-by-*n* vector

Nominal pressure drop used for calculating the pressure loss coefficient for rigid and flexible pipes, specified as a scalar or vector. All nominal values must be greater than 0 and must have the same number of elements as the **Nominal mass flow rate** parameter. When this parameter is supplied as a vector, the scalar value  $K_{loss}$  is determined as a least-squares fit of the vector elements.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

**Mass flow rate threshold for flow reversal — Mass flow rate threshold**

1e-6 kg/s (default) | positive scalar

Mass flow rate threshold for reversed flow. A transition region is defined around 0 kg/s between the positive and negative values of the mass flow rate threshold. Within this transition region, numerical smoothing is applied to the flow response. The threshold value must be greater than 0.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Nominal pressure drop vs. nominal mass flow rate.

**Reynolds number vector for turbulent Darcy friction factor — Vector of Reynolds numbers for tabular parameterization**

[400, 1000, 1500, 3000, 4000, 6000, 10000, 20000, 40000, 60000, 100000, 100000000] (default) | 1-by- $n$  vector

Vector of Reynolds numbers for the tabular parameterization of the Darcy friction factor. The vector elements form an independent axis with the **Darcy friction factor vector** parameter. The vector elements must be listed in ascending order. A positive Reynolds number corresponds to flow from port **A** to port **B**.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

**Darcy friction factor vector — Vector of friction factors for tabular parameterization**

[.264, .112, .071, .0417, .0387, .0268, .025, .0232, .0226, .022, .0214, .0214] (default) | 1-by- $n$  vector

Vector of Darcy friction factors for the tabular parameterization of the Darcy friction factor. The vector elements must correspond one-to-one with the elements in the **Reynolds number vector for turbulent Darcy friction factor** parameter, and must be unique and greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to Tabulated data - Darcy friction factor vs. Reynolds number.

**Laminar friction constant for Darcy friction factor — Friction constant for laminar flows**

64 (default) | positive scalar

Friction constant for laminar flows. The Darcy friction factor captures the contribution of wall friction in pressure loss calculations. If **Cross-sectional geometry** is not set to Custom, this parameter is internally set to 64.

**Dependencies**

To enable this parameter, set **Viscous friction parameterization** to either:

- Haaland correlation
- Tabulated data - Darcy friction factor vs. Reynolds number

and **Cross-sectional geometry** to Custom.

## Pipe Wall

### Pipe wall specification — Specifies wall flexibility

Rigid (default) | Flexible

Specifies wall flexibility. This parameter is independent of pipe cross-sectional geometry. The **Flexible** setting preserves the initial pipe shape and applies equal expansion of the cross-sectional area. It may not be accurate for non-circular cross-sectional geometry under high deformation.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

### Volumetric expansion specification — Linear expansion correlation

Cross-sectional area vs. pressure (default) | Hydraulic diameter vs. pressure

Linear expansion correlation. The settings correlate the new cross-sectional area or hydraulic diameter to the pipe pressure.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On and **Pipe wall specification** to Flexible.

### Static pressure-cross sectional area gain — Coefficient for area-dependent pipe deformation

$1e-6 \text{ m}^2/\text{MPa}$  (default) | positive scalar

Coefficient for calculating pipe deformation for the **Cross-sectional area vs. pressure** setting. The gain is multiplied by the pressure differential between the segment pressure and atmospheric pressure.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On, **Pipe wall specification** to Flexible, and **Volumetric expansion specification** to Cross-sectional area vs. pressure.

### Static pressure-hydraulic diameter gain — Coefficient for diameter-dependent pipe deformation

$1e-6 \text{ m}/\text{MPa}$  (default) | positive scalar

Coefficient for calculating pipe deformation for the **Hydraulic diameter vs. pressure** setting. The gain is multiplied by the pressure differential between the segment pressure and atmospheric pressure.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On, **Pipe wall specification** to Flexible, and **Volumetric expansion specification** to Hydraulic diameter vs. pressure.

### Volumetric expansion time constant — Pipe deformation time constant

$0.01 \text{ s}$  (default) | positive scalar

Time required for the wall to reach steady-state after pipe deformation. This parameter impacts the dynamic change in pipe volume.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On and **Pipe wall specification** to Flexible.

**Initial Conditions****Initial liquid pressure — Initial pressure in pipe or pipe segment**

0.101325 MPa (default) | positive scalar | 1-by- $n$  vector

Initial liquid pressure, specified as a scalar or vector. A vector  $n$  elements long defines the liquid pressure for each of  $n$  pipe segments. If the vector is two elements long, the pressure along the pipe is linearly distributed between the two element values. If the vector is three or more elements long, the initial pressure in the  $n$ th segment is set by the  $n$ th element of the vector.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On.

**Initial mass flow rate from port A to port B — Initial mass flow rate for inertia calculation**

0 kg/s (default) | scalar

Initial mass flow rate for pipes with simulated fluid inertia.

**Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On and **Fluid inertia** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

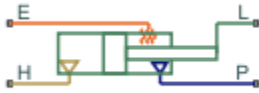
**See Also**

Partially Filled Pipe (IL) | Pipe (TL) | Pipe (IL) | Elbow (IL) | T-Junction (IL) | Tank (IL)



# Pneumo-Hydraulic Actuator

Double-acting cylinder operated by hydraulic and pneumatic power

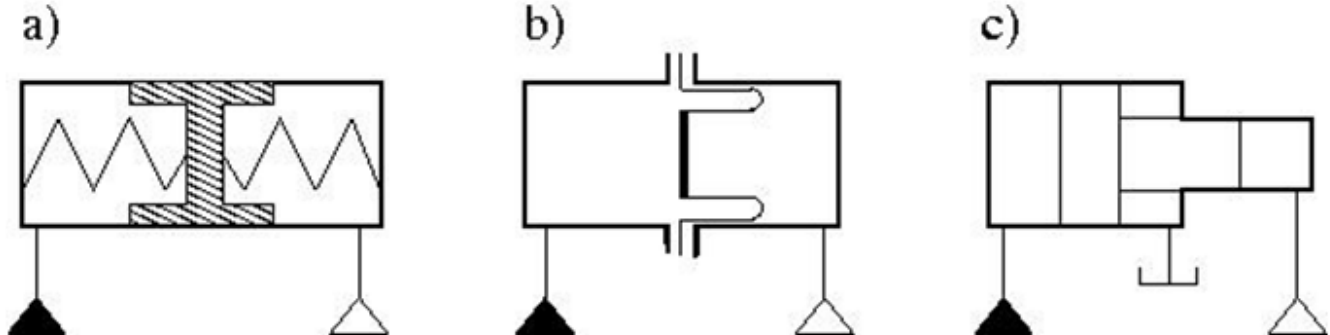


## Library

Hydraulic Cylinders

## Description

The Pneumo-Hydraulic Actuator block simulates a pneumo-hydraulic actuator, implemented as a double-acting cylinder with one side connected to a hydraulic power supply and another side operated by pneumatic power. Such devices are widely used as pneumo-hydraulic pumps, intensifiers, and converters of various types. The following illustration shows a few examples of the pneumo-hydraulic actuator: a) with rigid separator; b) with flexible separator; c) pneumo-hydraulic intensifier.



The block provides two main modeling variants, accessible by right-clicking the block in your block diagram and then selecting the appropriate option from the context menu, under **Simscape > Block choices**:

- **One mechanical port** — Use this variant to model just the load on the piston. In this case, the cylinder is assumed to be grounded.
- **Two mechanical ports** — Use this variant to model the load on the actuator cylinder, as well as the piston. This variant also lets you include liquid compressibility on the hydraulic side of the actuator.

### Configuration with One Mechanical Port

Use this variant of the block when the load is applied only to the piston and the cylinder clamping structure is grounded. The hydraulic part of the model accounts only for fluid consumption associated with the piston velocity. The pneumatic part of the model is built with the ideal gas relationships. To

simulate the limit on the piston motion, the hard stop is included in the model. The piston effective area is assumed to be constant. As a result, the model is described with the following equations:

$$q_H = A_H \cdot v$$

$$F_H = A_H \cdot p$$

$$F_P = A_P \cdot p$$

$$F_{HS} = \begin{cases} K \cdot (x - stroke) + D \cdot v & \text{for } x > stroke \\ K \cdot x + D \cdot v & \text{for } x < 0 \\ 0 & \text{for } 0 \leq x \leq stroke \end{cases}$$

$$F_H = F_P + F_{HS} + F_L$$

$$v = \frac{dx}{dt}$$

$$V_P = V_0 + A_P \cdot (stroke - x)$$

$$G = \frac{V_P}{RT} \left( \frac{dp}{dt} - \frac{p}{T} \frac{dT}{dt} \right) - \frac{A_P}{RT} p \cdot v$$

$$Q_P = \frac{c_v \cdot V_P}{R} \frac{dp}{dt} - \frac{c_p \cdot A_P}{R} p \cdot v + Q_{HE}$$

where

$q_H$	Hydraulic volumetric flow rate
$p$	Pressure in the actuator chambers
$A_H$	Hydraulic side effective area
$A_P$	Pneumatic side effective area
$v$	Piston velocity
$F_H$	Force developed by piston on hydraulic side
$F_P$	Force developed by piston on pneumatic side
$F_{HS}$	Hard stop force
$F_L$	Force developed by external load connected to port L
$K$	Hard stop stiffness
$D$	Hard stop damping
$stroke$	Piston stroke
$x$	Piston displacement
$V_P$	Chamber volume on pneumatic side
$V_0$	Chamber dead volume on pneumatic side
$G$	Gas mass flow rate
$R$	Gas constant
$T$	Gas absolute temperature

$Q_P$	Heat flow through the pneumatic chamber
$c_v$	Gas specific heat at constant volume
$c_p$	Gas specific heat at constant pressure
$Q_{HE}$	Heat flow through the thermal port E

The model is suitable for building pneumo-hydraulic or hydro-pneumatic pumps, intensifiers, and similar devices. You can simulate piston loading (such as inertia, springs, friction) by modeling the load externally and connecting it to port L. Similarly, simulate the heat exchange with the environment through the external thermal port E, which corresponds to the gas in the chamber. Use blocks from the Simscape Foundation library, such as the Convective Heat Transfer, Conductive Heat Transfer, Thermal Mass, and so on, depending on the actual system configuration.

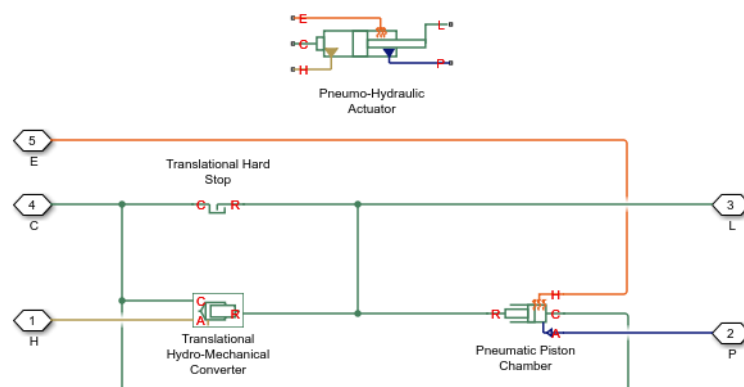
Port P is the pneumatic conserving port associated with the pneumatic side of the actuator. Port H is the hydraulic conserving port associated with the hydraulic inlet.

The block directionality assumes that pressure in the hydraulic chamber causes the piston to move in the positive direction, while pressure in the pneumatic chamber tends to move the piston in the negative direction. Flow rates are considered positive if they flow into the actuator.

### Configuration with Two Mechanical Ports

This variant of the block is suitable when the forces on both piston and cylinder are considered. This is a composite component and is built of the following blocks from the Simscape Foundation library:

- Translational Hydro-Mechanical Converter
- Pneumatic Piston Chamber
- Translational Hard Stop



Connections R and C are mechanical translational ports corresponding to the cylinder rod and cylinder clamping structure, respectively. Connection H is a hydraulic conserving port that is connected to the hydraulic Translational Hydro-Mechanical Converter. Connection P is a pneumatic conserving port that is connected to the pneumatic port of the Pneumatic Piston Chamber block. Connection E is a thermal conserving port associated with the gas in the pneumatic chamber. The fluid pressure, either on the hydraulic or pneumatic side, is transformed into mechanical energy through the converter. The piston (rod) motion is limited with the mechanical Translational Hard Stop block in such a way that the rod can travel only between cylinder caps. The fluid compressibility can also be taken into account on the hydraulic side.

You can control the block directionality using the **Converter orientation** parameter. If the **Converter orientation** is set to **Act in positive direction**, the pressure in the hydraulic chamber causes the piston to move in the positive direction, while the pressure in the pneumatic chamber tends to move the piston in the negative direction. Flow rates are considered positive if they flow into the actuator.

## Basic Assumptions and Limitations

- The effective piston area in each chamber is assumed to be constant.
- The leakage flow between chambers is assumed to be negligible because pressures in the chambers are equal.
- In **One mechanical port** configuration, on the hydraulic side, fluid compressibility is not taken into account. However, in **Two mechanical ports** configuration, you have an option to include fluid compressibility by setting the **Compressibility** parameter to **On**.
- On the pneumatic side, the mass flow rate and heat flow computations assume that the gas is ideal.
- In **One mechanical port** configuration, the cylinder is always assumed be grounded.
- In **Two mechanical ports** configuration, no loading on piston rod, such as inertia, friction, spring, and so on, is taken into account. If necessary, you can easily add them by connecting an appropriate building block to cylinder port R.

## Parameters

- “Hydraulic Side Tab” on page 1-1374
- “Pneumatic Side Tab” on page 1-1375
- “Hard Stop Tab” on page 1-1375

### Hydraulic Side Tab

#### Hydraulic side piston area

Effective piston area on the hydraulic side. The default value is  $2e-3 \text{ m}^2$ .

#### Stroke

Piston maximum travel between caps. The default value is  $0.2 \text{ m}$ .

#### Piston initial distance from hydraulic port H

The distance between the piston and the cap on the hydraulic side at the beginning of simulation. This value cannot exceed the piston stroke. The default value is  $0$ .

#### Compressibility

This parameter is visible only in the **Two mechanical ports** configuration. Specifies whether fluid density on the hydraulic side is taken as constant or varying with pressure. The default value is **Off**, in which case the block models an ideal transducer. If you select **On**, the block dialog box displays additional parameters that let you model dynamic variations of the liquid density without adding any extra blocks.

#### Hydraulic side dead volume

This parameter is visible only when the **Compressibility** parameter is set to **On**. Fluid volume in hydraulic chamber that remains in the chamber after the rod is fully retracted. The default value is  $1e-4 \text{ m}^3$ .

**Specific heat ratio**

This parameter is visible only when the **Compressibility** parameter is set to 0n. Gas-specific heat ratio. The default value is 1.4.

**Initial liquid pressure (relative)**

This parameter is visible only when the **Compressibility** parameter is set to 0n. The initial relative pressure of fluid in the hydraulic converter. This parameter specifies the initial condition for use in block's initial state at the beginning of a simulation run. The default value is 0.

**Converter orientation**

This parameter is visible only in the **Two mechanical ports** configuration. Specifies hydraulic cylinder orientation with respect to the globally assigned positive direction. The cylinder can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port H exerts force in negative direction, set the parameter to **Acts in negative direction**. The default value is **Acts in positive direction**.

**Pneumatic Side Tab****Pneumatic side piston area**

Effective piston area on the pneumatic side. The default value is  $1e-3 \text{ m}^2$ .

**Pneumatic side dead volume**

Gas volume in pneumatic chamber that remains in the chamber after the rod is fully retracted. The default value is  $1e-4 \text{ m}^3$ .

**Initial gas pressure (absolute)**

The initial absolute gas pressure in the pneumatic chamber. The default value is 101325 Pa.

**Initial gas temperature**

The initial gas temperature in the pneumatic chamber. The default value is 293.15 K.

**Hard Stop Tab****Hard stop stiffness**

The hard stop model implemented in the block assumes that the stop resists penetration of the piston with force proportional to the penetration. This parameter sets the stiffness of the contact between the stop and the piston. The default value is  $1e6 \text{ N/m}$ .

**Hard stop damping**

The damping in the hard stop model accounts for dissipation in the piston-stop contact. The default value is  $150 \text{ N*s/m}$ .

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Compressibility**
- **Converter orientation**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the values of the **Compressibility** parameter at the time the model entered Restricted mode.

## Ports

The block has the following ports:

H

Hydraulic conserving port associated with the actuator hydraulic chamber.

P

Pneumatic conserving port associated with the actuator pneumatic chamber.

E

Thermal conserving port associated with the gas in the pneumatic chamber. You can simulate the heat exchange with the environment through this port.

L

Mechanical translational conserving port associated with the actuator piston. You can model the load on the piston, such as external force, inertia, friction, or spring, and connect it through this port.

R

Mechanical translational conserving port associated with the actuator clamping structure, which is exposed by selecting the **Two mechanical ports** variant. You can model the load on the actuator casing through this port.

## Version History

**Introduced in R2012b**

# Poppet Valve

Hydraulic poppet valve

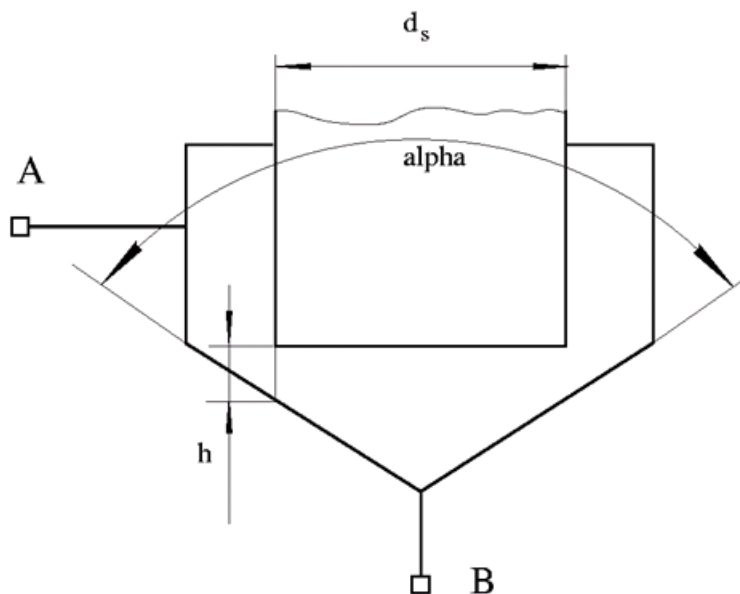


## Library

Flow Control Valves

## Description

The Poppet Valve block models a variable orifice created by a cylindrical sharp-edged stem and a conical seat.



The flow rate through the valve is proportional to the valve opening and to the pressure differential across the valve. The flow rate is determined according to the following equations:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

$$\Delta p = p_A - p_B,$$

$$h = x_0 + x$$

$$h_{\max} = d_s \frac{\sqrt{1 + \cos \frac{\alpha}{2}} - 1}{\sin \alpha}$$

$$A(h) = \begin{cases} A_{\text{leak}} & \text{for } h < = 0 \\ \pi \cdot \left( d_s + h \cdot \sin \frac{\alpha}{2} \cdot \cos \frac{\alpha}{2} \right) \cdot h \cdot \sin \frac{\alpha}{2} + A_{\text{leak}} & \text{for } 0 < h < h_{\max} \\ A_{\max} + A_{\text{leak}} & \text{for } h > = h_{\max} \end{cases}$$

$$A_{\max} = \frac{\pi d_s^2}{4}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A(h)$	Instantaneous orifice passage area
$x_0$	Initial opening
$x$	Stem displacement from initial position
$h$	Valve opening
$h_{\max}$	Maximum valve opening. The passage area remains constant and equal to $A_{\max}$ after this.
$d_s$	Stem diameter
$\alpha$	Cone angle
$\rho$	Fluid density
$A_{\text{leak}}$	Closed valve leakage area
$A_{\max}$	Maximum valve open area
$p_{\text{cr}}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{\text{cr}}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = (p_{\text{avg}} + p_{\text{atm}})(1 - B_{\text{lam}})$$

$$p_{\text{avg}} = (p_A + p_B)/2$$

where

$p_{\text{avg}}$	Average pressure between the block terminals
$p_{\text{atm}}$	Atmospheric pressure, 101325 Pa
$B_{\text{lam}}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)



- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Valve instantaneous hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S opens the valve.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- The flow passage area is assumed to be equal to the frustum side surface area.

## Parameters

### Valve stem diameter

The diameter of the valve stem. The default value is 0.01 m.

### Seat cone angle

The angle of the valve conical seat. The parameter value must be in the range between 0 and 180 degrees. The default value is 120 degrees.

### Initial opening

The initial opening of the valve. The parameter value must be nonnegative. The default value is 0.

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.65.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### **Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to `Pressure ratio`.

### **Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 10. This parameter is visible only if the **Laminar transition specification** parameter is set to `Reynolds number`.

### **Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

## **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

S

Physical signal port to control spool displacement.

## **Version History**

Introduced in R2006a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Ball Valve | Gate Valve | Needle Valve | Pressure-Compensated Flow Control Valve

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Poppet Valve (IL)

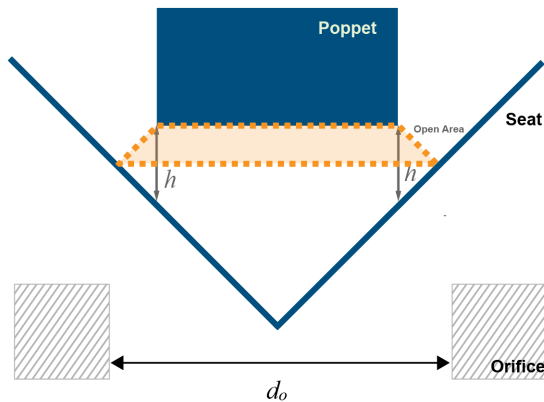
Poppet valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves

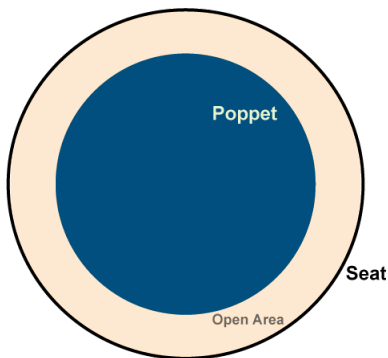


## Description

The Poppet Valve (IL) block represents a flow-control valve in an isothermal liquid system. The poppet can either be a cylinder or a ball. You can choose between sharp-edged and conical seats. The poppet opens or closes according to the displacement signal at port **S**. A positive signal retracts the poppet and opens the valve.



## Poppet Valve Schematic



## Poppet Valve Top View

### Cylindrical Stem Poppet Opening Area

The opening area of the valve is calculated as:

$$A_{open} = \pi h \sin\left(\frac{\theta}{2}\right) \left[ d_s + \frac{h}{2} \sin(\theta) \right] + A_{leak},$$

where:

- $h$  is the vertical distance between the outer edge of the cylinder and the seat, indicated in the schematic above.
- $\theta$  is the **Seat cone angle**.
- $d_s$  is the **Stem diameter**.
- $A_{leak}$  is the **Leakage area**.

The opening area is bounded by the maximum displacement  $h_{max}$ :

$$h_{max} = \frac{d_s \left[ \sqrt{1 + \cos\left(\frac{\theta}{2}\right)} - 1 \right]}{\sin(\theta)}.$$

For any stem displacement larger than  $h_{max}$ ,  $A_{open}$  is the sum of the maximum orifice area and the **Leakage area**:

$$A_{open} = \frac{\pi}{4} d_s^2 + A_{leak}.$$

For any combination of the signal at port **S** and the cylinder offset less than 0, the minimum valve area is the **Leakage area**.

## Round Ball Poppet Opening Area

### Sharp-edged Seat Geometry

The opening area of the valve is calculated as:

$$A_{open, sharp-edged} = \pi r_O \sqrt{(G_{sharp} + h)^2 + r_O^2} \left[ 1 - \frac{r_B^2}{(G_{sharp} + h)^2 + r_O^2} \right] + A_{leak},$$

where:

- $h$  is the vertical distance between the outer edge of the cylinder and the seat, indicated in the schematic above.
- $r_O$  is the seat orifice radius, calculated from the **Seat orifice diameter**.
- $r_B$  is the radius of the ball, calculated from the **Ball diameter**.
- $G_{sharp}$  is the geometric parameter:  $G_{sharp} = \sqrt{r_B^2 - r_O^2}$ .
- $A_{leak}$  is the **Leakage area**.

The opening area is bounded by the maximum displacement  $h_{max}$ :

$$h_{max} = \sqrt{\frac{2r_B^2 - r_O^2 + r_O \sqrt{r_O^2 + 4r_B^2}}{2}} - G_{sharp}.$$

For any ball displacement larger than  $h_{max}$ ,  $A_{open}$  is the sum of the maximum orifice area and the **Leakage area**:

$$A_{open} = \frac{\pi}{4}d_O^2 + A_{leak}.$$

For any combination of the signal at port **S** and the ball offset that is less than 0, the minimum valve area is the **Leakage area**.

**Conical Seat Geometry**

The opening area of the valve is calculated as:

$$A_{open, conical} = G_{conical}h + \frac{\pi}{2}\sin(\theta)\sin\left(\frac{\theta}{2}\right)h^2 + A_{leak},$$

where:

- $h$  is the vertical distance between the outer edge of the cylinder and the seat, indicated in the schematic above.
- $\theta$  is the **Seat cone angle**.
- $G_{conical}$  is the geometric parameter:  $G_{conical} = \pi r_B \sin(\theta)$ , where  $r_B$  is the ball radius.
- $A_{leak}$  is the **Leakage area**.

The opening area is bounded by the maximum displacement  $h_{max}$ :

$$h_{max} = \frac{\sqrt{r_B^2 + \frac{r_O^2}{\cos\left(\frac{\theta}{2}\right)} - r_B}}{\sin\left(\frac{\theta}{2}\right)}.$$

For any ball displacement larger than  $h_{max}$ ,  $A_{open}$  is the sum of the maximum orifice area and the **Leakage area**:

$$A_{open} = \frac{\pi}{4}d_O^2 + A_{leak}.$$

For any combination of the signal at port **S** and the ball offset that is less than 0, the minimum valve area is the **Leakage area**.

**Numerically Smoothed Displacement**

The block calculates the poppet displacement,  $h$ , such that

$$h = \begin{cases} 0, & (S - S_{min}) \leq 0 \\ h_{Max}, & (S - S_{min}) \geq h_{Max} \\ (S - S_{min}), & \text{Else} \end{cases}$$

where:

- $S$  is the physical signal input.
- $S_{min}$  is the **Poppet position when in the seat** parameter.
- $h_{Max}$  is the maximum displacement.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the poppet displacement between 0 and  $h_{Max}$ .

For more information, see “Numerical Smoothing”.

### Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_B = 0.$$

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{\text{valve}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2\right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{\text{crit}}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{\text{valve}}$  is the current valve open area.
- $A_{\text{port}}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{\text{crit}}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{\text{crit}}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{\text{crit}} = \frac{\pi \bar{\rho}}{8 A_{\text{valve}}} \left( \frac{\nu Re_{\text{crit}}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{\text{loss}}$  is calculated as:

$$PR_{\text{loss}} = \frac{\sqrt{1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{\text{valve}}}{A_{\text{port}}}}{\sqrt{1 - \left(\frac{A_{\text{valve}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{\text{valve}}}{A_{\text{port}}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** to Off. In this case,  $PR_{\text{loss}}$  is 1.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port to the valve.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port to the valve.

### **Input**

#### **S — Stem displacement, m**

physical signal

Displacement of the valve control member in m, specified as a physical signal..

### **Parameters**

#### **Poppet geometry — Type of poppet**

Cylindrical stem (default) | Round ball

Type of poppet. You can choose either a cylindrical or ball-shaped control member.

#### **Valve seat specification — Geometry of valve seat**

Sharp-edged (default) | Conical

Geometry of valve seat. The block uses this parameter to calculate the open area between the poppet and seat.

#### **Dependencies**

To enable this parameter, set **Poppet geometry** to Round ball.

#### **Ball diameter — Diameter of ball control member**

0.01 m (default) | positive scalar

Diameter of the ball control member.

#### **Dependencies**

To enable this parameter, set **Poppet geometry** to Round ball.

#### **Seat orifice diameter — Seat orifice diameter**

7e-3 m (default) | positive scalar

Seat orifice diameter.

#### **Dependencies**

To enable this parameter, set **Poppet geometry** to Round ball.

#### **Stem diameter — Diameter of cylindrical stem**

0.01 m (default) | positive scalar

Diameter of the cylindrical stem.

#### **Dependencies**

To enable this parameter, set **Poppet geometry** to Cylindrical stem.

#### **Seat cone angle — Angle of seat opening**

120 deg (default) | positive scalar

Angle of the seat opening.



**Dependencies**

To enable this parameter, set either:

- **Poppet geometry** to `Cylindrical stem`
- **Poppet geometry** to `Round ball` and **Valve seat specification** to `Conical`

**Poppet position when in the seat – Control member offset**

0 m (default) | positive scalar

Poppet offset when valve is closed. A positive, nonzero value indicates a partially open valve. A negative, nonzero value indicates an overlapped valve that remains closed for an initial displacement set by the physical signal at port **S**.

**Leakage area – Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Cross-sectional area at ports A and B – Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Pressure recovery – Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

**Version History**

Introduced in R2020a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Poppet Valve (G) | Poppet Valve (TL) | Needle Valve (IL) | Gate Valve (IL)

# Poppet Valve (TL)

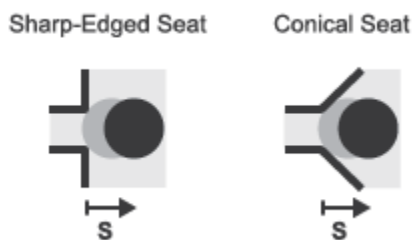
Poppet flow control valve in a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Flow Control Valves



## Description

The Poppet Valve (TL) block represents the flow control within a thermal liquid network. You can specify the seat geometry as either sharp-edged or conical. Set the poppet displacement with the physical signal at port **S**.



## Mass Balance

The mass conservation equation in the valve is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate into the valve through port **A**.
- $\dot{m}_B$  is the mass flow rate into the valve through port **B**.

## Momentum Balance

The pressure differential over the valve is:

$$p_A - p_B = \frac{\dot{m} \sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{2\rho_{Avg} C_d^2 S^2} \left[ 1 - \left( \frac{S_R}{S} \right)^2 \right] PR_{Loss},$$

where:

- $p_A$  is the pressure at port **A**.
- $p_B$  is the pressure at port **B**.
- $\dot{m}$  is the mass flow rate.

- $\rho_{Avg}$  is the average liquid density.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\dot{m}_{cr}$  is the critical mass flow rate:

$$\dot{m}_{cr} = Re_{cr} \mu_{Avg} \sqrt{\frac{\pi}{4} S_R}.$$

where:

- $Re_{cr}$  is the value of the **Critical Reynolds number** parameter.
- $\mu_{Avg}$  is the average fluid dynamic viscosity.
- $S$  is the value of the **Cross-sectional area at port A and B** parameter.
- $PR_{Loss}$  is the pressure ratio:

$$PR_{Loss} = \frac{\sqrt{1 - (S_R/S)^2 (1 - C_d^2)} - C_d(S_R/S)}{\sqrt{1 - (S_R/S)^2 (1 - C_d^2)} + C_d(S_R/S)}.$$

### Energy Balance

The energy conservation equation in the valve is

$$\phi_A + \phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate into the valve through port **A**.
- $\phi_B$  is the energy flow rate into the valve through port **B**.

### Opening Area With a Sharp-Edged Seat

When you set **Valve seat specification** to Sharp-edged, the block calculates the valve opening area using

$$A = \pi r_o \left( 1 - \left( \frac{r_p}{d_{OB}} \right)^2 \right) d_{OB}(h) + A_{leak},$$

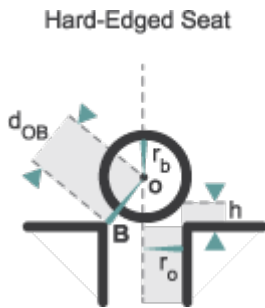
where:

- $r_o$  is the valve orifice radius.
- $r_p$  is the valve poppet radius.
- $d_{OB}(h)$  is the distance between the center of the poppet and the edge of the orifice. This distance is a function of the valve lift,  $h$ .
- $A_{leak}$  is the leakage area.

The maximum displacement,  $h_{max}$ , is

$$h_{max} = \sqrt{\frac{2r_p^2 - r_o^2 + r_o \sqrt{r_o^2 + 4r_p^2}}{2}} - \sqrt{r_p^2 - r_o^2}.$$

The figure shows a schematic of a hard-edged seat.



### Opening Area With a Conical Seat

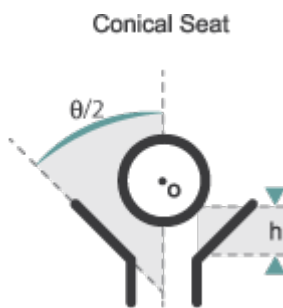
When you set **Valve seat specification** to `Conical`, the block calculates the valve opening area using a geometric relationship, such that

$$A = \pi r_p \sin(\theta) h + \frac{\pi}{2} \sin\left(\frac{\theta}{2}\right) \sin(\theta) h^2 + A_{leak}.$$

The maximum displacement,  $h_{max}$ , is:

$$h_{max} = \frac{\sqrt{r_p^2 + \frac{r_o^2}{\cos\left(\frac{\theta}{2}\right)} - r_p}}{\sin\left(\frac{\theta}{2}\right)},$$

where  $\theta$  is the **Cone angle**. The figure shows a schematic of a conical seat.



### Numerically Smoothed Displacement

The block calculates the poppet displacement,  $h$ , such that

$$h = \begin{cases} 0, & (S - S_{min}) \leq 0 \\ h_{Max}, & (S - S_{min}) \geq h_{Max} \\ (S - S_{min}), & \text{Else} \end{cases}$$

where:

- $S$  is the physical signal input.
- $S_{min}$  is the **Poppet position when in the seat** parameter.
- $h_{Max}$  is the maximum displacement.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the poppet displacement between  $\theta$  and  $h_{Max}$ .

For more information, see “Numerical Smoothing”.

## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port associated with valve inlet A.

#### B — Liquid port

thermal liquid

Thermal liquid conserving port associated with valve inlet B.

### Input

#### S — Poppet displacement, m

physical signal

Physical signal port associated with the displacement of the poppet, in m.

## Parameters

### Valve seat specification — Geometry of valve seat

Sharp-edged (default) | Conical

Geometry of the valve seat. The block uses this parameter to calculate the open area between the poppet and seat.

### Cone angle — Angle of seat opening

120 deg (default) | positive scalar

Angle of the seat opening.

### Dependencies

To enable this parameter, set **Valve seat specification** to Conical.

### Ball diameter — Poppet diameter

0.01 m (default) | positive scalar

Diameter of the poppet.

### Orifice diameter — Seat orifice diameter

7e-3 m (default) | positive scalar

Seat orifice diameter.

### Poppet position when in the seat — Poppet offset

0 m (default) | nonnegative scalar

Poppet offset when valve is shut. A positive, nonzero value indicates a partially open valve. A negative, nonzero value indicates an overlapped valve that remains shut for an initial displacement set by the physical signal at port **S**.

**Leakage area — Gap area when in fully closed position**

1e-12 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully shut position. The block saturates smaller numbers to this value. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Smoothing factor — Gap area when in fully closed position**

0.01 (default) | scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in the near-open or near-shut positions. Set this value to a nonzero number less than one to increase the stability of your simulation in these regimes.

**Cross-sectional area at ports A and B — Area at conserving ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area at ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient — Discharge coefficient**

0.7 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Gate Valve (TL)

## Porting Plate Variable Orifice

Variable orifice between piston and porting plate

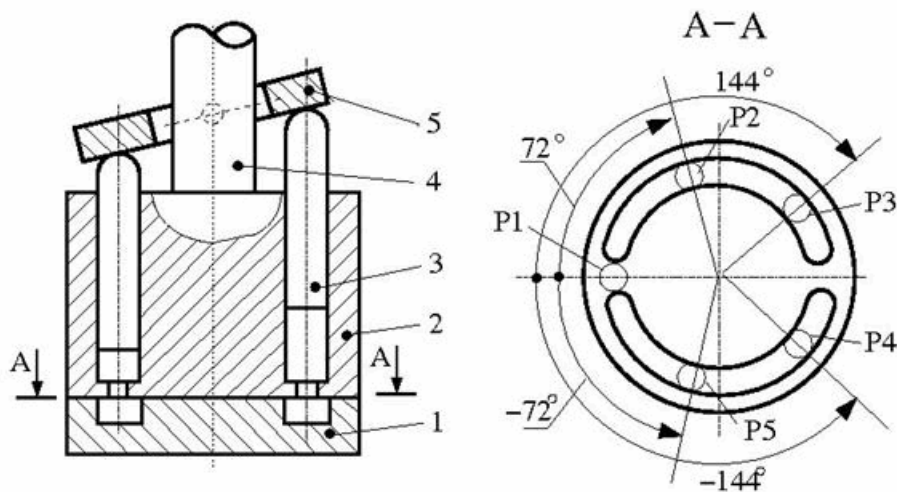


## Library

Pumps and Motors

## Description

Porting plate is a key element of axial-piston machines. Its objective is to provide communication between pistons and pump ports during the rotor, or cylinder block, rotation. The porting plate is equipped with two crescent-shaped slots, one of which is connected to the intake port while the other is channeled to the discharge port. The pistons are carried along the porting plate slots, thus periodically connecting the piston to either the intake or the discharge port of the machine.

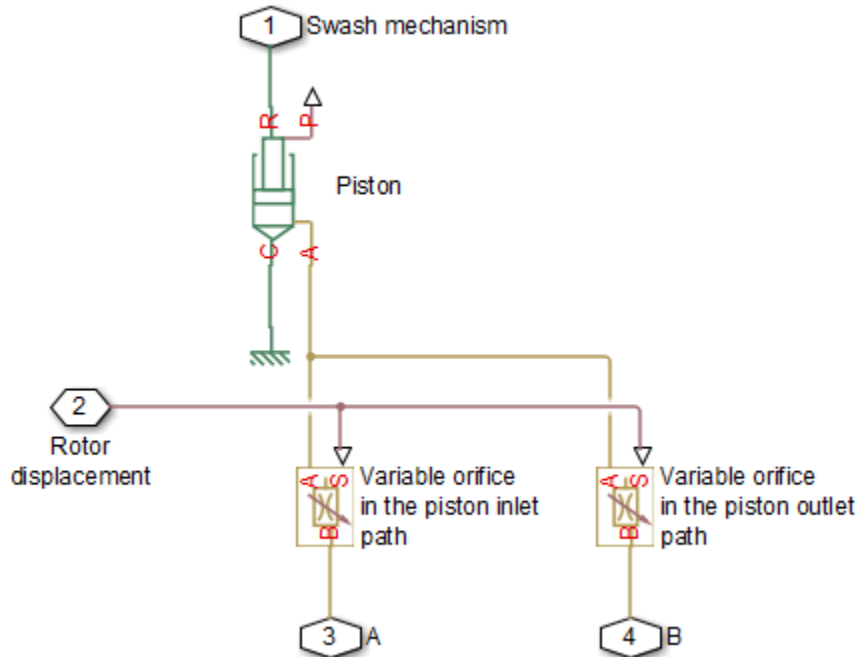


The preceding diagram shows an axial-piston machine with five pistons, where:

- 1 Porting plate
- 2 Rotor
- 3 Piston
- 4 Driving shaft
- 5 Swash plate

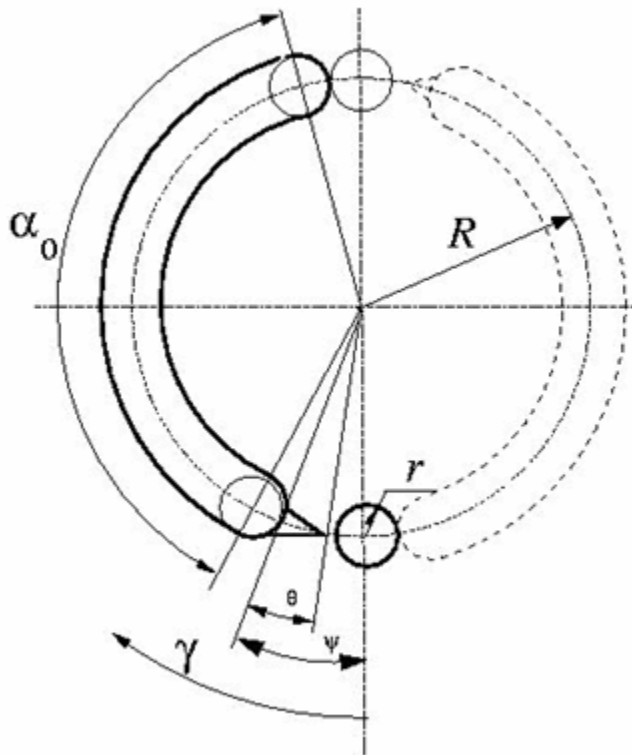


During rotor rotation, every piston gets connected to one of the porting slots. These piston connections, modeled as variable orifices, are reflected in the schematic model of a piston, shown in the following illustration.



The Porting Plate Variable Orifice block is a model of a variable orifice created between the piston chamber and a slot on a porting plate. Two Porting Plate Variable Orifice blocks are necessary in the model of a piston, to simulate connection to the intake and the discharge port, respectively.

The calculation diagram of the porting plate variable orifice is shown in the next illustration.



The model assumes that the slot is shifted by a pressure carryover angle  $\psi$  from the reference point in the direction of orifice rotation. Generally,  $r/R \leq \psi \leq 3 \cdot r/R$ , where  $r$  is the orifice radius and  $R$  is the piston pitch radius. A small triangular-shaped transition slot is placed at the beginning of the major slot, to avoid sudden pressure change. To avoid direct connection between the intake and discharge slots, the transition slot angle  $\theta$  must be less than  $\psi - r/R$ . The transition slot area is assumed to be linearly dependent on the rotation angle and characterized by its maximum area. There are six distinctive angles defining the relationship between the rotation angle  $\gamma$  and the orifice opening, as listed in the following table.

No	Nomenclature	Value	Description
1	$\gamma_1$	$\psi - \theta - r/R$	Opening of transition slot starts.
2	$\gamma_2$	$\psi - r/R$	Opening of the major slot starts. The orifice contacts with the transition slot.
3	$\gamma_3$	$\psi + r/R$	Major slot full opening starts.
4	$\gamma_4$	$\psi + r/R + 0.01$	Transition slot ends.
5	$\gamma_5$	$\pi - 2 \cdot r/R$	Major slot full opening ends.
6	$\gamma_6$	$\pi$	Major slot opening ends.

The variable orifice is fully opened in the  $\alpha_0$  region

$$\psi + r/R \leq \gamma \leq \pi - 2 \cdot r/R$$

where  $\gamma$  is the rotation angle.

The orifice area is computed with the following equations:

$$\begin{aligned}
 A &= A_{leak} && \text{for } \gamma_6 < \gamma \leq \gamma_1 \\
 A &= G \cdot (\gamma - \gamma_1) + A_{leak} && \text{for } \gamma_1 < \gamma \leq \gamma_2 \\
 A &= A_{tr} + r^2(\beta - \sin\beta) + A_{leak} && \text{for } \gamma_2 < \gamma \leq \gamma_3 \\
 A &= A_{tr} \cdot (1 - 100 \cdot (\gamma - \gamma_3)) + \pi \cdot r^2 + A_{leak} && \text{for } \gamma_3 < \gamma \leq \gamma_4 \\
 A &= \pi \cdot r^2 + A_{leak} && \text{for } \gamma_4 < \gamma \leq \gamma_5 \\
 A &= r^2(\beta - \sin\beta) + A_{leak} && \text{for } \gamma_5 < \gamma \leq \gamma_6 \\
 \beta &= \begin{cases} 2 \cdot \arccos(R/r \cdot \sin(0.5 \cdot (\gamma_3 - \gamma))) & \text{for } \gamma_2 < \gamma \leq \gamma_3 \\ 2 \cdot \arccos(R/r \cdot \sin(0.5 \cdot (2 \cdot r/R + \gamma - \pi))) & \text{for } \gamma_5 < \gamma \leq \gamma_6 \end{cases}
 \end{aligned}$$

where

$A$	Orifice area
$A_{tr}$	Transition slot maximum area
$A_{leak}$	Closed orifice leakage area

After the area has been determined, the flow rate through the orifice is computed with the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$\Delta p = p_A - p_B,$$

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$D_H$	Orifice hydraulic diameter
$\rho$	Fluid density
$\nu$	Fluid kinematic viscosity
$p_{cr}$	Minimum pressure for turbulent flow
$Re_{cr}$	Critical Reynolds number

The Porting Plate Variable Orifice block model is essentially a building block intended for use in various piston machines. The model accounts for the flow regime by computing the Reynolds number and comparing it with its critical value. No inertial effects are considered in the model.

Connections A and B are hydraulic conserving ports associated with the inlet and outlet of the orifice. Connection G is a physical signal port associated with the input signal for the cylinder block angle. The input signal at port G is treated as an angle, in radians, therefore it is essential that the input signal representing angular displacement is kept within the range from 0 to  $2\pi$ . Connect port G to the output port of an Angle Sensor block to meet this requirement.

The flow rate is considered positive if it flows from A to B. At initial position, the orifice is assumed to be shifted by the pressure carryover angle from the slot. When the block rotates in the positive direction, the orifice starts opening. To adjust the initial position of the orifice with respect to the slot, use the **Phase angle** parameter.

## Basic Assumptions and Limitations

- The model accounts for the viscous friction in the piston-plate contact.
- No inertial effects are considered.
- The plate angular displacements are considered to be small.
- The joint between the piston and the plate permanently maintains contact between the piston and the plate.

## Parameters

### Piston pitch radius

The radius of the pitch circle where the pistons are located. The parameter must be greater than zero. The default value is 0.05 m.

### Orifice diameter

The diameter of the orifice at the bottom of the piston chamber. The parameter must be greater than zero. The default value is 0.005 m.

### Pressure carryover angle

The angle introduced between to slot and the orifice to avoid abrupt pressure change and decrease leakage. This angle is marked  $\psi$  in the preceding calculation diagram. The angle is expected to be in the range  $r/R \leq \psi \leq 3 \cdot r/R$ , where  $r$  is the orifice radius and  $R$  is the piston pitch radius. The default value is 0.06 rad.

### Phase angle

This parameter sets the orifice initial angular position with respect to the slot. The default value is 0, which means that the orifice is shifted by the pressure carryover angle from the slot.

### Transition slot angle

The angle covered by a small, triangular-shaped transition slot placed before the major slot to avoid sudden pressure change, as shown in the preceding calculation diagram. To avoid direct connection between the intake and discharge slots, the transition slot angle  $\theta$  must be less than  $\psi - r/R$ . The default value is 0.01 rad.

### Transition slot maximum area

The maximum cross-sectional area of the transition slot. The slot area is assumed to be linearly-dependent on the rotation angle and reaches its maximum when the orifice approaches the major slot. The default value is  $1e-6$  m.

**Flow discharge coefficient**

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.6.

**Critical Reynolds number**

The maximum Reynolds number for laminar flow. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges.

**Leakage area**

The total area of possible leaks in the completely closed orifice. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-9 \text{ m}^2$ .

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

G

Physical signal input port that conveys the angular position of the orifice to the block. The signal applied to the port is treated as an angle, in radians, and must be in the range between 0 and  $2\pi$ .

**Examples**

The “Hydraulic Axial-Piston Pump with Load-Sensing and Pressure-Limiting Control” example models a test rig designed to investigate interaction between an axial-piston pump and a typical control unit, simultaneously performing the load-sensing and pressure-limiting functions. To assure required accuracy, the model of the pump must account for such features as interaction between pistons, swash plate, and porting plate, which makes it necessary to build a detailed pump model.

**Version History**

**Introduced in R2011a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Angle Sensor | Swash Plate

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Positive-Displacement Compressor (2P)

Two-phase fluid positive-displacement compressor in a thermodynamic cycle

**Library:** Simscape / Fluids / Two-Phase Fluid / Fluid Machines

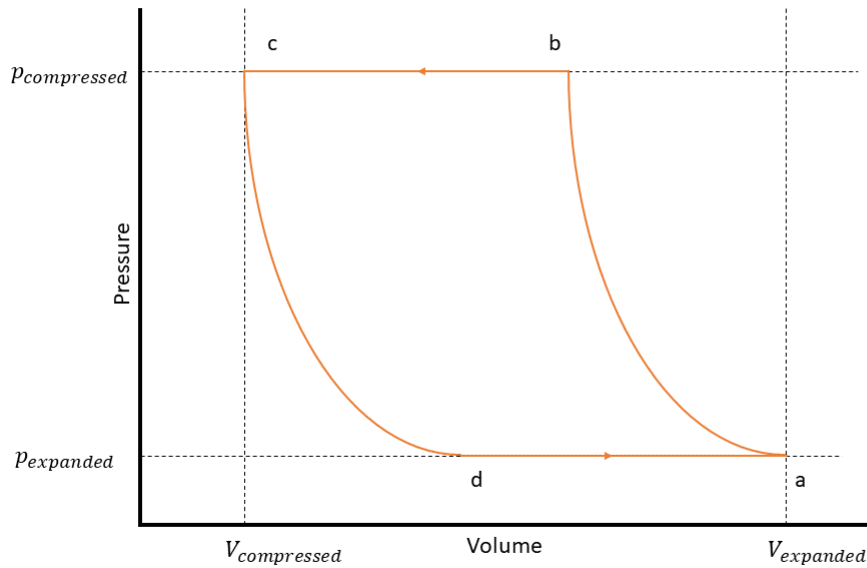


### Description

The Positive-Displacement Compressor (2P) block represents a positive-displacement compressor, such as reciprocating piston, rotary screw, rotary vane, and scroll, in a two-phase fluid network. You can control how the block parameterizes a positive displacement compressor by setting **Parameterization** to **Analytical** or **Tabulated**. Port **R** and port **C** are mechanical rotational conserving ports associated with the compressor shaft and casing, respectively. When there is positive rotation at port **R** with respect to port **C**, two-phase fluid flows from port **A** to port **B**. The block may not be accurate for reversed flow.

The block treats the positive displacement process as polytropic such that  $p v^n$  is constant, where  $p$  is pressure,  $v$  is specific volume, and  $n$  is the **Polytropic exponent** parameter. You can use the block to model isentropic processes by setting  $n$  equal to the isentropic exponent,  $k$ . The figure shows the steps of a positive-displacement compressor on a P-V diagram, which has these states:

- $a$  — The compressor cylinder is full at inlet pressure.
- $b$  — The pressure inside the compressor exceeds that of the outlet, which results in fluid discharge.
- $c$  — The compressor reaches the top of the piston stroke, and only the clearance volume remains in the cylinder.
- $d$  — The pressure inside the cylinder drops below the inlet pressure, which results in fluid intake.



### Efficiency

When you set **Volumetric efficiency parameterization** to Analytical, the block calculates the volumetric efficiency as

$$\eta_V = 1 + C - C \left( \frac{P_{out}}{P_{in}} \right)^{1/n},$$

where the block implements the polytropic pressure-volume relationship. The block calculates the clearance volume fraction,  $C$ , as

$$C = \frac{1 - \eta_{V,nominal}}{p_{ratio}^{1/n} - 1},$$

where  $\eta_{V,nominal}$  is the **Nominal volumetric efficiency** parameter, and  $p_{ratio}$  is the ratio of saturation pressures that correspond to **Nominal condensing temperature** and **Nominal evaporating temperature**.

When you set **Volumetric efficiency parameterization** to

Tabulated, the block interpolates the values of the **Volumetric efficiency table, eta(w,pr)** parameter as a function of the shaft speed and the pressure ratio.

### Continuity Equations

The block calculates the mass flow rate as

$$\dot{m} = \eta_V \omega \frac{V_{disp}}{v_s},$$



where

- $\dot{m}$  is the mass flow rate.
- $\omega$  is the angular velocity of port **R** relative to port **C**.
- $v_s$  is the specific volume at the inlet.
- $V_{disp}$  is the displacement volume that the block uses.

When you set **Displacement specification** to Volumetric displacement, the block uses the **Displacement volume** parameter. When you set **Displacement specification** to Nominal mass flow rate and shaft speed, the block calculates the displacement volume as

$$V_{disp} = \frac{\dot{m}_{nominal} v_{s, nominal}}{\omega_{nominal} \eta_{V, nominal}},$$

where

- $\dot{m}_{nominal}$  is the **Nominal mass flow rate** parameter.
- $\omega_{nominal}$  is the **Nominal shaft speed** parameter.
- $\eta_{V, nominal}$  is the **Nominal volumetric efficiency** parameter.

The block calculates the nominal inlet specific volume,  $v_s$ , based upon the **Nominal conditions specification** parameter. When you select Nominal pressure ratio, the block uses the **Nominal inlet pressure** and **Nominal inlet temperature** parameters. When you select Nominal evaporating and condensing temperatures, the block uses the **Nominal evaporating temperature** and **Nominal evaporator superheat** parameters.

The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_A$  and  $\dot{m}_B$  are the mass flow rates of ports **A** and **B**, respectively. The block conserves energy such that

$$\phi_A + \phi_B + \dot{m}_A \Delta h_t = 0,$$

where  $\Delta h_t$  is the change in specific total enthalpy, and  $\dot{m}_A \Delta h_t$  is the fluid power.

The block equates the fluid power to the polytropic power such that

$$\eta_M \tau = \frac{n}{n-1} \eta_V p_{in} V_{disp} \left[ \left( \frac{p_{out}}{p_{in}} \right)^{\frac{n-1}{n}} - 1 \right],$$

where  $\eta_M$  is the **Mechanical efficiency** parameter, and  $\tau$  is the shaft torque.

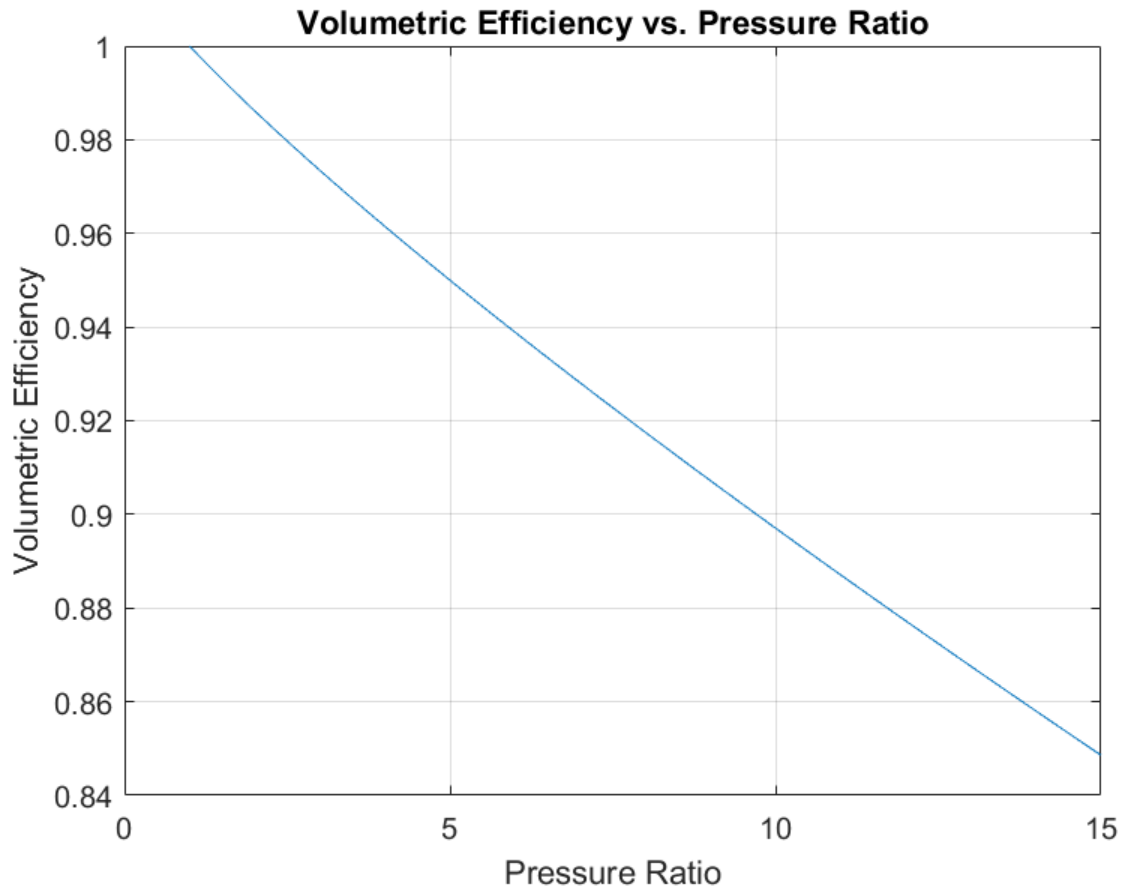
### Visualizing the Volumetric Efficiency

To visualize the block volumetric efficiency, right-click the block and select **Fluids > Plot Volumetric Efficiency**.

Each time you modify the block settings, click **Reload Data** on the figure window.

When you set **Volumetric efficiency parameterization** to Analytical, the block plots compressor volumetric efficiency vs. pressure ratio.

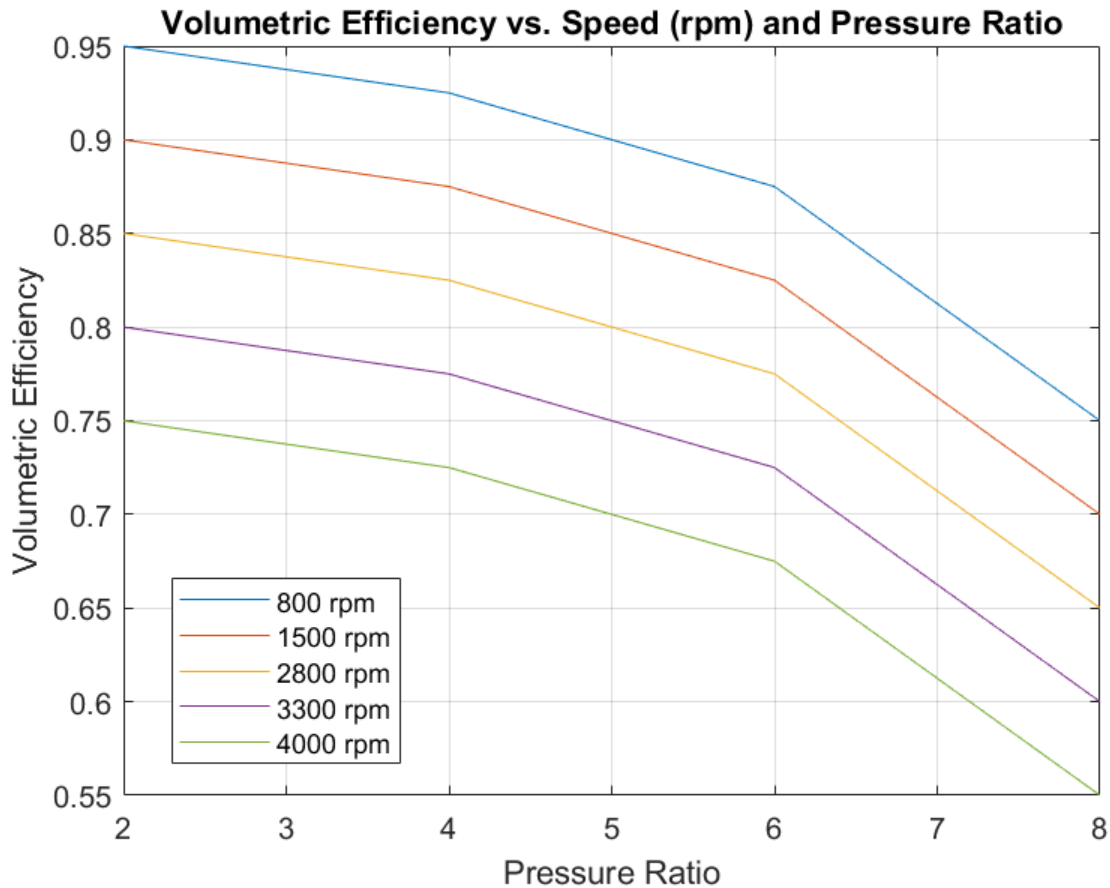
Reload Data



#### Analytical Parameterization Default Volumetric Efficiency

When you set **Volumetric efficiency parameterization** to Tabulated, the block plots compressor volumetric efficiency vs. pressure ratio for each entry in the **Shaft speed vector,  $w$** .

Reload Data



### Tabulated Parameterization Default Volumetric Efficiency

#### Assumptions and Limitations

- The block may not be accurate for flow from port **B** to port **A**.
- The block assumes that the flow is quasi-steady: the compressor does not accumulate mass.
- The block is designed to operate in superheated vapor. The block may not be accurate in two-phase mixture or subcooled liquid.

#### Ports

##### Conserving

##### **A – Compressor inlet**

two-phase fluid

Two-phase fluid conserving port associated with the compressor inlet.

##### **B – Compressor outlet**

two-phase fluid

Two-phase fluid conserving port associated with the compressor outlet.

**C – Compressor casing**

mechanical rotational

Mechanical rotational conserving port associated with the compressor case.

**R – Compressor shaft**

mechanical rotational

Mechanical rotational conserving port associated with the compressor shaft.

**Parameters****Displacement specification – Option to specify displacement by volume or nominal conditions**

Volumetric displacement (default) | Nominal mass flow rate and shaft speed

Whether to specify the fluid displacement according to volume per cycle or nominal condition values.

**Displacement volume – Displacement volume**130 cm<sup>3</sup>/rev (default) | positive scalar

Fluid volume displaced per cycle. The block defines a cycle as one compression stroke and one expansion stroke, which occur during a single crank shaft revolution. This volume is the difference between the maximum cylinder volume and the clearance volume, ( $V_a - V_c$ ). In general, the displacement volume is the volume swept out by the compressor over one shaft revolution.

**Dependencies**

To enable this parameter, set **Displacement specification** to Volumetric displacement.

**Nominal conditions specification – Option to specify pressure ratio or refrigeration cycle saturation temperatures**

Nominal pressure ratio (default) | Nominal evaporating and condensing temperatures

Whether to specify the nominal conditions that determine the displacement volume using the nominal outlet to inlet pressure ratio or the nominal evaporating and condensing temperatures.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal mass flow rate – Nominal mass flow rate**

0.01 kg/s (default) | positive scalar

Nominal mass flow rate that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal shaft speed – Nominal shaft speed**

1000 rpm (default) | positive scalar

Nominal shaft speed that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal inlet pressure – Nominal inlet pressure**

0.101325 MPa (default) | positive scalar

Nominal inlet pressure that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed and **Nominal conditions specification** to Nominal pressure ratio.

**Nominal inlet temperature – Nominal inlet temperature**

373.15 K (default) | positive scalar

Nominal inlet temperature that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed and **Nominal conditions specification** to Nominal pressure ratio.

**Nominal evaporating temperature – Nominal evaporating temperature**

373.15 K (default) | positive scalar

Nominal evaporating temperature that the block uses to find the displacement volume. This is the saturation temperature in the evaporator. The block assumes the nominal compressor inlet pressure is the pressure that corresponds to this saturation temperature.

The evaporating temperature is also known as the saturated suction temperature, or SST.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed and **Nominal conditions specification** to Nominal evaporating and condensing temperatures.

**Nominal condensing temperature – Nominal condensing temperature**

398.15 K (default)

Nominal condensing temperature that the block uses to find the displacement volume. This is the saturation temperature in the condenser. The block assumes that the nominal compressor outlet pressure is the pressure that corresponds to this saturation temperature.

The condensing temperature is also known as the saturated discharge temperature, or SDT.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed and **Nominal conditions specification** to Nominal evaporating and condensing temperatures.

**Nominal evaporator superheat – Nominal saturation excess temperature**

10 deltaK (default) | scalar

Nominal excess temperature beyond the saturation point in the evaporator outlet, which the block assumes to be connected to the compressor inlet.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal evaporating and condensing temperatures.

**Volumetric efficiency parameterization – Option to parameterize volumetric efficiency analytically or using tables**

Analytical (default) | Tabulated

Whether to parameterize the displacement volumetric efficiency using analytical equations or tabulated data.

**Nominal volumetric efficiency – Nominal volumetric efficiency**

0.95 (default) | positive scalar

Nominal volumetric efficiency to compute the clearance volume fraction. The nominal volumetric efficiency is the volumetric efficiency when the compressor operates at nominal conditions.

**Dependencies**

To enable this parameter, set **Volumetric efficiency parameterization** to Analytical.

**Nominal pressure ratio – Nominal pressure ratio**

5 (default)

Nominal pressure ratio to compute the clearance volume fraction.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal pressure ratio and **Volumetric efficiency parameterization** to Analytical.

**Shaft speed vector, w – Shaft speed vector**

[800, 1500, 2800, 3300, 4000] rpm (default) | vector of length M

Vector of shaft speeds corresponding to the compressor volumetric efficiency. Each element corresponds to a row of the **Volumetric efficiency table, eta(w,pr)** parameter.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal pressure ratio and **Volumetric efficiency parameterization** to Tabulated.

**Pressure ratio vector, pr – Pressure ratio vector**

[2, 4, 6, 8] (default) | vector of length N

Vector of pressure ratios corresponding to the compressor volumetric efficiency. Each element corresponds to a column of the **Volumetric efficiency table, eta(w,pr)** parameter.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal pressure ratio and **Volumetric efficiency parameterization** to Tabulated.

**Volumetric efficiency table, eta(w,pr) — Volumetric efficiency**

[.95, .9, .85, .8, .75; .925, .875, .825, .775, .725; .875, .825, .775, .725, .675; .75, .7, .65, .6, .55] (default) | M-by-N matrix

Volumetric efficiency for a given shaft speed and pressure ratio.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal pressure ratio and **Volumetric efficiency parameterization** to Tabulated.

**Polytropic exponent — Polytropic exponent**

1.2 (default) | positive scalar

Exponent that the block uses when implementing the polytropic pressure-volume relationship.

**Mechanical efficiency — Compressor mechanical efficiency**

0.9 (default) | positive scalar

Ratio of the fluid power to the mechanical shaft power.

**Inlet area at port A — Inlet area**

0.01 m<sup>2</sup> (default) | positive scalar

Inlet area associated with port A.

**Outlet area at port B — Outlet area**

0.01 m<sup>2</sup> (default) | positive scalar

Outlet area associated with port B.

**Report when fluid is not fully vapor — Two-phase fluid condition check**

None (default) | Warning | Error

Action to perform when the fluid at port A does not meet vapor conditions.

## Version History

Introduced in R2022a

## References

[1] Mitchell and Braun, Principles of Heating, Ventilation, and Air Conditioning in Buildings, chap. SM6, 2012.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Positive-Displacement Compressor (G) | Compressor (2P)

## Positive-Displacement Compressor (G)

Positive displacement compressor in a gas network

**Library:** Simscape / Fluids / Gas / Turbomachinery



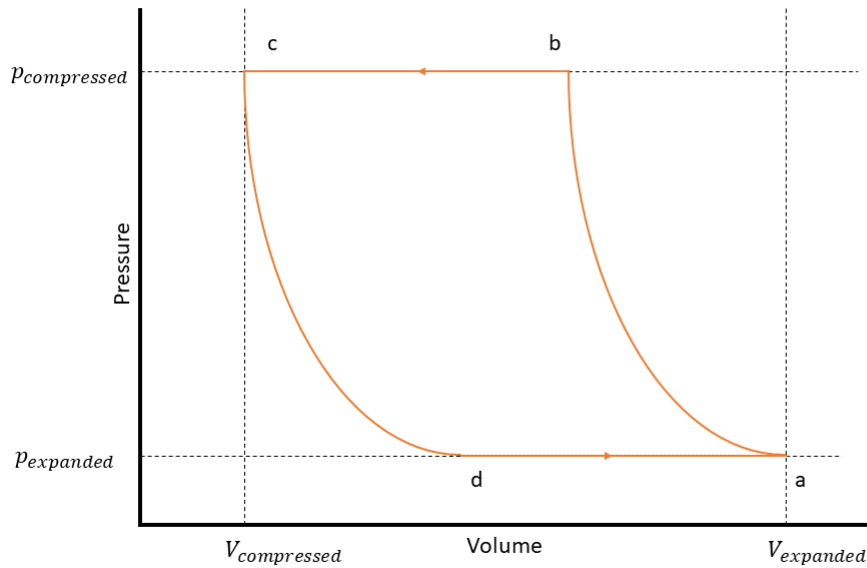
### Description

The Positive-Displacement Compressor (G) block represents a positive-displacement compressor, such as reciprocating piston, rotary screw, rotary vane, and scroll, in a gas network. You can control how the block parameterizes a positive displacement compressor by setting **Parameterization** to **Analytical** or **Tabulated**. Port **R** and port **C** are mechanical rotational conserving ports associated with the compressor shaft and casing, respectively. When there is positive rotation at port **R** with respect to port **C**, gas flows from port **A** to port **B**. The block may not be accurate for reversed flow.

The block treats the positive displacement process as polytropic such that  $pv^n$  is constant, where  $p$  is pressure,  $v$  is specific volume, and  $n$  is the **Polytropic exponent** parameter. You can use the block to model isentropic processes by setting  $n$  equal to the isentropic exponent,  $k$ . The figure shows the steps of a piston compressor on a P-V diagram, which has these states:

- $a$  — The compressor cylinder is full at inlet pressure.
- $b$  — The pressure inside the compressor exceeds that of the outlet, which results in fluid discharge.
- $c$  — The compressor reaches the top of the piston stroke, and only the clearance volume remains in the cylinder.
- $d$  — The pressure inside the cylinder drops below the inlet pressure, which results in fluid intake.





### Efficiency

When you set **Volumetric efficiency parameterization** to Analytical, the block calculates the volumetric efficiency as

$$\eta_V = 1 + C - C \left( \frac{P_{out}}{P_{in}} \right)^{1/n},$$

where the block implements the polytropic pressure-volume relationship. The block calculates the clearance volume fraction,  $C$ , as

$$C = \frac{1 - \eta_{V,nominal}}{p_{ratio}^{1/n} - 1},$$

where  $\eta_{V,nominal}$  is the **Nominal volumetric efficiency** parameter, and  $p_{ratio}$  is the ratio of saturation pressures that correspond to the **Nominal inlet pressure** and **Nominal inlet temperature** parameters.

When you set **Volumetric efficiency parameterization** to

Tabulated, the block interpolates the values of the **Volumetric efficiency table, eta(w,pr)** parameter as a function of the shaft speed and the pressure ratio.

### Continuity Equations

The block calculates the mass flow rate as

$$\dot{m} = \eta_V \omega \frac{V_{disp}}{v_s},$$

where

- $\dot{m}$  is the mass flow rate.
- $\omega$  is the angular velocity of port **R** relative to port **C**.
- $v_s$  is the specific volume at the inlet.
- $V_{disp}$  is the displacement volume that the block uses.

When you set **Displacement specification** to `Volumetric displacement`, the block uses the **Displacement volume** parameter. When you set **Displacement specification** to `Nominal mass flow rate and shaft speed`, the block calculates the displacement volume as

$$V_{disp} = \frac{\dot{m}_{nominal} v_{s,nominal}}{\omega_{nominal} \eta_{V,nominal}},$$

where

- $\dot{m}_{nominal}$  is the **Nominal mass flow rate** parameter.
- $\omega_{nominal}$  is the **Nominal shaft speed** parameter.
- $\eta_{V,nominal}$  is the **Nominal volumetric efficiency** parameter.

The block calculates the nominal inlet specific volume,  $v_s$ , based upon the **Nominal conditions specification** parameter. When you select `Nominal pressure ratio`, the block uses the **Nominal inlet pressure** and **Nominal inlet temperature** parameters.

The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_A$  and  $\dot{m}_B$  are the mass flow rates of ports **A** and **B**, respectively. The block conserves energy such that

$$\phi_A + \phi_B + \dot{m}_A \Delta h_t = 0,$$

where  $\Delta h_t$  is the change in specific total enthalpy, and  $\dot{m}_A \Delta h_t$  is the fluid power.

The block equates the fluid power to the polytropic power such that

$$\eta_M \tau = \frac{n}{n-1} \eta_V p_{in} V_{disp} \left[ \left( \frac{p_{out}}{p_{in}} \right)^{\frac{n-1}{n}} - 1 \right],$$

where  $\eta_M$  is the **Mechanical efficiency** parameter, and  $\tau$  is the shaft torque.

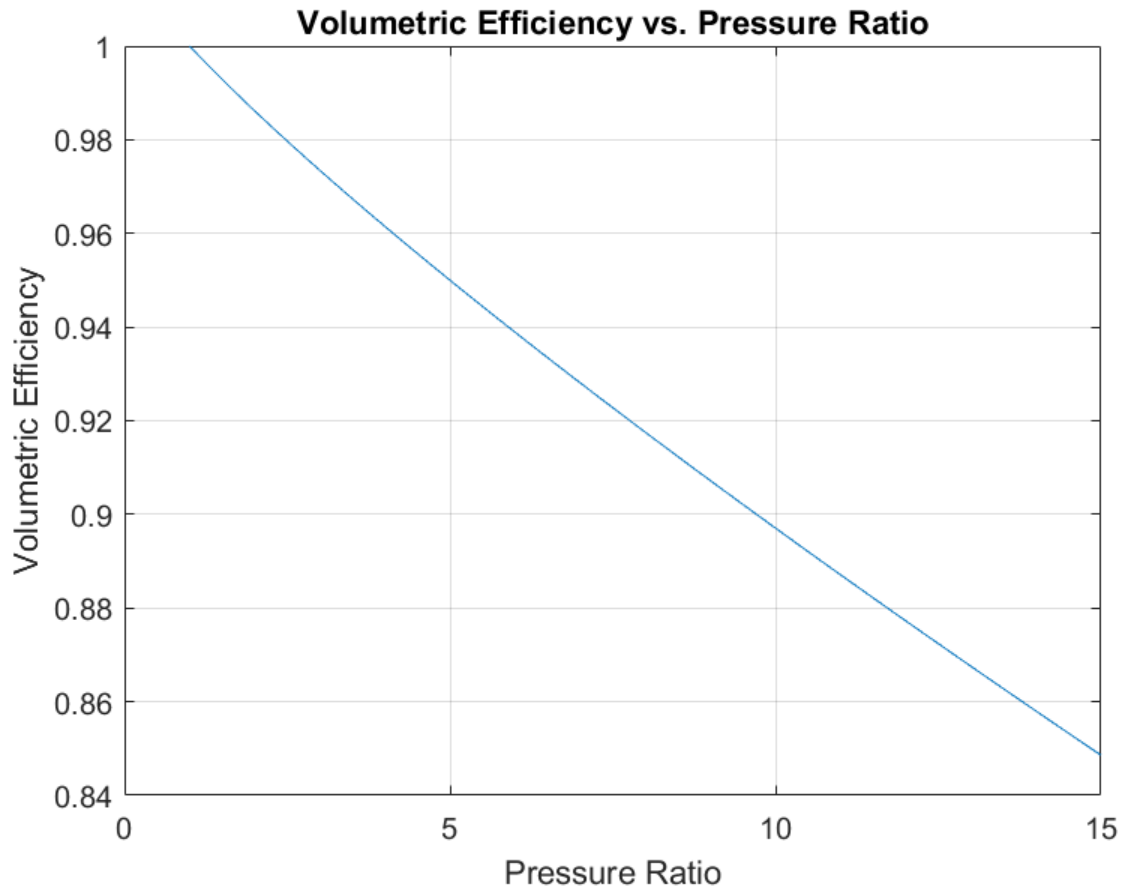
### Visualizing the Volumetric Efficiency

To visualize the block volumetric efficiency, right-click the block and select **Fluids > Plot Volumetric Efficiency**.

Each time you modify the block settings, click **Reload Data** on the figure window.

When you set **Volumetric efficiency parameterization** to `Analytical`, the block plots compressor volumetric efficiency vs. pressure ratio.

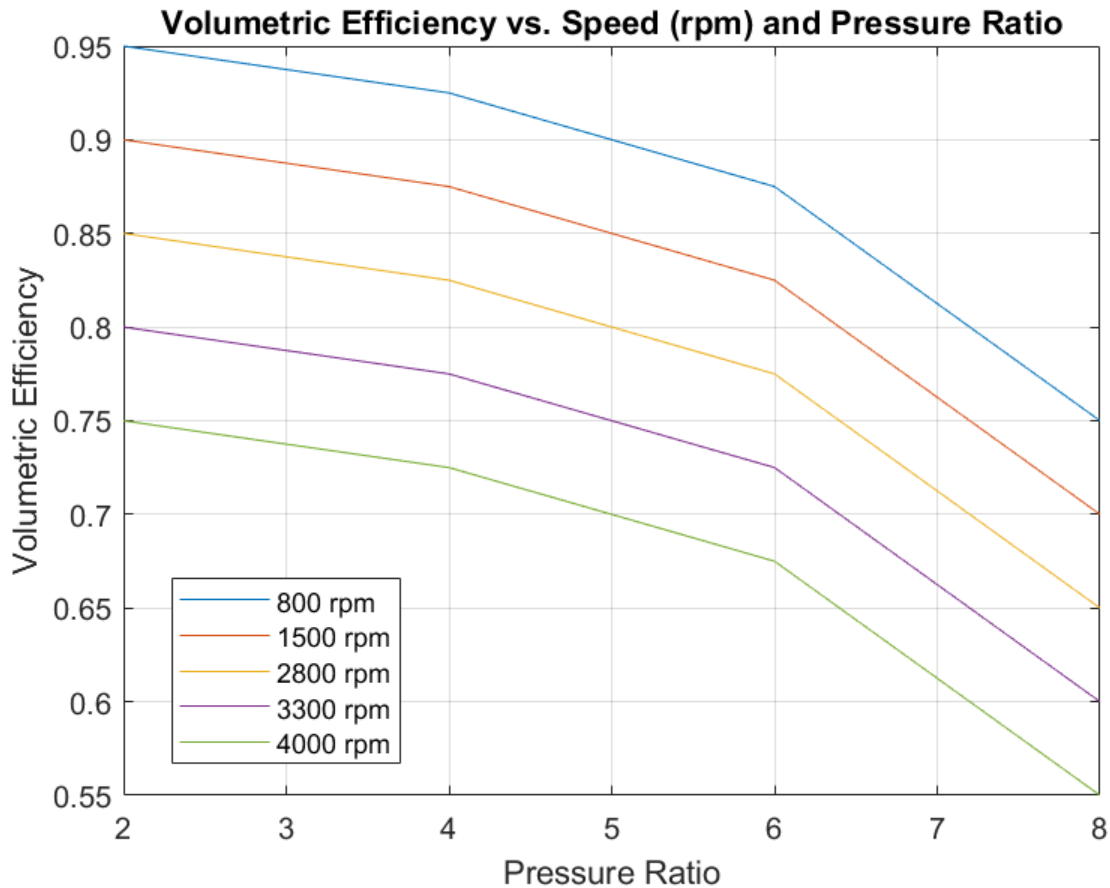
Reload Data



#### Analytical Parameterization Default Volumetric Efficiency

When you set **Volumetric efficiency parameterization** to Tabulated, the block plots compressor volumetric efficiency vs. pressure ratio for each entry in the **Shaft speed vector, w**.

## Reload Data

**Tabulated Parameterization Default Volumetric Efficiency****Assumptions and Limitations**

- The block may not be accurate for flow from port **B** to port **A**.
- The block assumes that the flow is quasi-steady; the compressor does not accumulate mass.

**Ports****Conserving****A – Compressor inlet**

gas

Gas conserving port associated with the compressor inlet.

**B – Compressor outlet**

gas

Gas conserving port associated with the compressor outlet.

**C – Compressor casing**

mechanical rotational

Mechanical rotational conserving port associated with the compressor case.

**R – Compressor shaft**

mechanical rotational

Mechanical rotational conserving port associated with the compressor shaft.

**Parameters****Displacement specification – Option to specify displacement by volume or nominal conditions**

Volumetric displacement (default) | Nominal mass flow rate and shaft speed

Whether to specify the fluid displacement according to volume per cycle or nominal condition values.

**Displacement volume – Displacement volume**130 cm<sup>3</sup>/rev (default) | positive scalar

Fluid volume displaced per cycle. The block defines a cycle as one compression stroke and one expansion stroke, which occur during a single crank shaft revolution. This volume is the difference between the maximum cylinder volume and the clearance volume, ( $V_a - V_c$ ). In general, the displacement volume is the volume swept out by the compressor over one shaft revolution.

**Dependencies**

To enable this parameter, set **Displacement specification** to Volumetric displacement.

**Nominal mass flow rate – Nominal mass flow rate**

0.01 kg/s (default) | positive scalar

Nominal mass flow rate that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal shaft speed – Nominal shaft speed**

1000 rpm (default) | positive scalar

Nominal shaft speed that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal inlet pressure – Nominal inlet pressure**

0.101325 MPa (default) | positive scalar

Nominal inlet pressure that the block uses the find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Nominal inlet temperature – Nominal inlet temperature**

293.15 K (default) | positive scalar

Nominal inlet temperature that the block uses to find the displacement volume.

**Dependencies**

To enable this parameter, set **Displacement specification** to Nominal mass flow rate and shaft speed.

**Volumetric efficiency parameterization – Option to parameterize volumetric efficiency analytically or using tables**

Analytical (default) | Tabulated

Whether to parameterize the displacement volumetric efficiency using analytical equations or tabulated data.

**Nominal volumetric efficiency – Nominal volumetric efficiency**

0.95 (default) | positive scalar

Nominal volumetric efficiency to compute the clearance volume fraction. The nominal volumetric efficiency is the volumetric efficiency when the compressor operates at nominal conditions.

**Dependencies**

To enable this parameter, set **Volumetric efficiency parameterization** to Analytical.

**Nominal pressure ratio – Nominal pressure ratio**

5 (default) | positive scalar

Nominal pressure ratio to compute the clearance volume fraction.

**Dependencies**

To enable this parameter, set **Nominal conditions specification** to Nominal pressure ratio and **Volumetric efficiency parameterization** to Analytical.

**Pressure ratio vector, pr – Pressure ratio vector**

[2, 4, 6, 8] (default) | vector of length N

Vector of pressure ratios corresponding to the compressor volumetric efficiency. Each element corresponds to a column of the **Volumetric efficiency table, eta(w,pr)** parameter.

**Dependencies**

To enable this parameter, set **Volumetric efficiency parameterization** to Tabulated.

**Shaft speed vector, w – Shaft speed vector**

[800, 1500, 2800, 3300, 4000] rpm (default) | vector of length M

Vector of shaft speeds corresponding to the compressor volumetric efficiency. Each element corresponds to a row of the **Volumetric efficiency table, eta(w,pr)** parameter.

**Dependencies**

To enable this parameter, set **Volumetric efficiency parameterization** to Tabulated.

**Volumetric efficiency table,  $\eta(w,pr)$  — Volumetric efficiency**

[.95, .9, .85, .8, .75; .925, .875, .825, .775, .725; .875, .825, .775, .725, .675; .75, .7, .65, .6, .55] (default) | M-by-N matrix

Volumetric efficiency for a given shaft speed and pressure ratio.

**Dependencies**

To enable this parameter, set **Volumetric efficiency parameterization** to Tabulated.

**Polytropic exponent — Polytropic exponent**

1.2 (default) | positive scalar

Exponent that the block uses when implementing the polytropic pressure-volume relationship.

**Mechanical efficiency — Compressor mechanical efficiency**

0.9 (default) | positive scalar

Ratio of the fluid power to the mechanical shaft power.

**Inlet area at port A — Inlet area**

0.01 m<sup>2</sup> (default) | positive scalar

Inlet area associated with port **A**.

**Outlet area at port B — Outlet area**

0.01 m<sup>2</sup> (default) | positive scalar

Outlet area associated with port **B**.

## Version History

Introduced in R2022a

## References

[1] Mitchell and Braun, Principles of Heating, Ventilation, and Air Conditioning in Buildings, chap. SM6, 2012.

## Extended Capabilities

**C/C++ Code Generation**

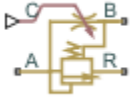
Generate C and C++ code using Simulink® Coder™.

**See Also**

Positive-Displacement Compressor (2P) | Compressor (G)

# Pressure-Compensated 3-Way Flow Control Valve

Hydraulic pressure compensating 3-way valve

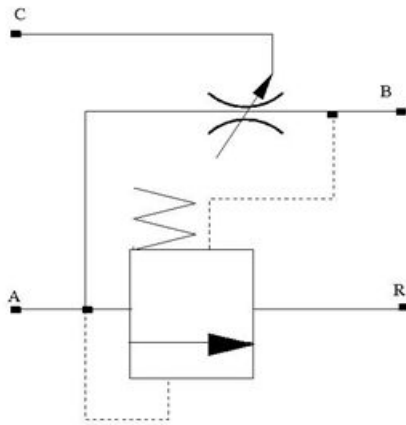


## Library

Flow Control Valves

## Description

The Pressure-Compensated 3-Way Flow Control Valve block represents a 3-way pressure-compensated flow control valve as a data-sheet-based model. The valve model includes a variable orifice and a normally closed pressure-control valve, connected in parallel with the orifice. The purpose of the pressure-control valve is to maintain a preset pressure differential across the orifice by diverting some flow from port A to the tank (port R) if the pressure differential exceeds the preset value. Port C controls the orifice opening, as shown in the following figure.



Depending on data listed in the manufacturer's catalogs or data sheets for your particular valve, you can choose one of the following model parameterization options:

- By maximum area and opening — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.
- By area vs. opening table — Use this option if the catalog or data sheet provides a table of the orifice passage area based on the control member displacement  $A=A(h)$ .

In the first case, the passage area is assumed to be linearly dependent on the control member displacement, that is, the orifice is assumed to be closed if the initial orifice opening is set to zero and the control member position also equals zero. The maximum orifice opening takes place at the



maximum displacement. In the second case, the passage area is determined by one-dimensional interpolation from the table  $A=A(h)$ .

The pressure-control valve representation does not account for inertia, friction, or hydraulic forces. The valve has the following area-pressure differential relationship:

$$A_{pc} = \begin{cases} A_{leak} & \text{for } p < p_{set} \\ (p - p_{set}) \frac{A_{max\_pc}}{p_{reg}} & \text{for } p_{set} \leq p \leq (p_{set} + p_{reg}) \\ A_{max\_pc} & \text{for } p > (p_{set} + p_{reg}) \end{cases}$$

where

$A_{pc}$	Pressure-control valve passage area
$p$	Pressure differential across the orifice
$p_{set}$	Preset pressure differential
$p_{reg}$	Regulation range
$A_{max\_pc}$	Pressure-control valve maximum area
$A_{leak}$	Closed orifice leakage area for pressure compensator

Both for the variable orifice and the pressure compensator, a small leakage area is assumed to exist even after the orifice is completely closed. Physically, it represents a possible clearance in the closed valve, but the main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or "hanging" part of the system could affect computational efficiency and even cause failure of computation.

After the area has been determined, the block computes the flow rate for both the orifice and the pressure compensator according to the following equations:

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$A = \begin{cases} A_{pc} & \text{for pressure compensator} \\ A_{or} & \text{for variable orifice} \end{cases}$$

$$A_{pc} = \begin{cases} h \cdot A_{max}/h_{max} + A_{leak} & \text{for } h > 0 \\ A_{leak} & \text{for } h < = 0 \end{cases}$$

$$h = x_0 + x$$

$$p = \begin{cases} p_A - p_R & \text{for pressure compensator} \\ p_A - p_B & \text{for variable orifice} \end{cases}$$

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B, p_R$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A$	Instantaneous orifice passage area
$A_{\max}$	Orifice maximum area
$A_{\text{leak}}$	Closed orifice leakage area
$h_{\max}$	Control member maximum displacement
$x_0$	Initial opening
$x$	Control member displacement from initial position
$h$	Orifice opening
$\rho$	Fluid density
$\nu$	Fluid kinematic viscosity
$p_{\text{cr}}$	Minimum pressure for turbulent flow
$Re_{\text{cr}}$	Critical Reynolds number
$D_H$	Instantaneous orifice hydraulic diameter

Connections A, B, and R are the conserving hydraulic ports associated with the valve inlet, outlet, and return, respectively. Connection C is a physical signal port through which the orifice opening is controlled. The block positive direction is from port A to port B. Positive signal at port C opens the valve.

## Assumptions and Limitations

Fluid inertia and pressure compensator loading are not taken into account.

## Parameters

- “Variable Orifice Tab” on page 1-1420
- “Pressure Compensator Tab” on page 1-1422

### Variable Orifice Tab

#### Orifice parameterization

Select one of the following methods for specifying the orifice:

- **By maximum opening and area** — Provide values for the maximum orifice area and the maximum orifice opening. The passage area is linearly dependent on the control member displacement, that is, the orifice is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By orifice area vs. orifice opening table** — Provide tabulated data of orifice openings and corresponding orifice areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

**Orifice maximum area**

The area of a fully opened orifice. The parameter value must be greater than zero. The default value is  $1e-4 \text{ m}^2$ . This parameter is used if **Orifice parameterization** is set to **By maximum opening and area**.

**Orifice maximum opening**

The maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $0.005 \text{ m}$ . This parameter is used if **Orifice parameterization** is set to **By maximum opening and area**.

**Tabulated orifice openings**

Vector of input values for orifice openings, specified as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in mm, are  $[-6, 0, 1, 3, 6, 9, 15]$ . This parameter is used if **Orifice parameterization** is set to **By orifice area vs. orifice opening table**. **Tabulated orifice openings** values will be used together with **Tabulated orifice area** values for one-dimensional table lookup.

**Tabulated orifice area**

Vector of orifice areas, specified as a one-dimensional array. The vector must be the same size as the orifice openings vector. All the values must be positive. The default values, in  $\text{cm}^2$ , are  $[1e-7, 1e-6, 0.08, 0.145, 0.96, 1, 1.001]$ . This parameter is used if **Orifice parameterization** is set to **By orifice area vs. orifice opening table**.

**Interpolation method**

This parameter is used if **Orifice parameterization** is set to **By orifice area vs. orifice opening table**. Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

**Extrapolation method**

This parameter is used if **Orifice parameterization** is set to **By orifice area vs. orifice opening table**. Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page.

**Orifice initial opening**

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or 0 for zero-lap configuration. The default value is 0.

**Orifice flow discharge coefficient**

Semi-empirical coefficient that is used in the computation of flow rate through the orifice. Its value depends on the geometrical properties of the orifice and usually is provided in textbooks or manufacturer data sheets. The default value is 0.6.

**Orifice laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Orifice laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Orifice critical Reynolds number** parameter.

**Orifice laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Orifice laminar transition specification** parameter is set to **Pressure ratio**.

**Orifice critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Orifice laminar transition specification** parameter is set to **Reynolds number**.

**Orifice leakage area**

The total area of possible leaks in the completely closed orifice. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-9 \text{ m}^2$ .

**Pressure Compensator Tab****Pressure differential across orifice setting**

Pressure difference that must be maintained across the variable orifice by the pressure compensator. The default value is  $6e5 \text{ Pa}$ .

**Pressure differential regulation range**

Pressure increase over the preset level needed to fully open the pressure compensator orifice. The lower the value of the range, the higher the valve sensitivity. The default value is  $0.5e5 \text{ Pa}$ .

**Pressure compensator maximum area**

The area of a fully opened pressure compensator. The parameter value must be greater than zero. The default value is  $1e-4 \text{ m}^2$ .

**Pressure compensator flow discharge coefficient**

Semi-empirical coefficient that is used in the computation of flow rate through the pressure compensator. The default value is 0.6.

**Pressure compensator laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Pressure compensator laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Pressure compensator critical Reynolds number** parameter.

#### **Pressure compensator laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Pressure compensator laminar transition specification** parameter is set to **Pressure ratio**.

#### **Pressure compensator critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Pressure compensator laminar transition specification** parameter is set to **Reynolds number**.

#### **Pressure compensator leakage area**

The total area of possible leaks in the completely closed orifice. Must be greater than 0. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The default value is  $1e-9$  m<sup>2</sup>.

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Interpolation method**
- **Extrapolation method**
- **Orifice laminar transition specification**
- **Pressure compensator laminar transition specification**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

### **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

### **Ports**

The block has the following ports:

- A Hydraulic conserving port associated with the valve inlet.
- B Hydraulic conserving port associated with the valve outlet.
- R Hydraulic conserving port that connects with the tank.
- C Physical signal control port.

## **Version History**

**Introduced in R2013b**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Pressure-Compensated Flow Control Valve

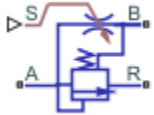
### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Pressure-Compensated 3-Way Flow Control Valve (IL)

3-way flow control in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



## Description

The Pressure-Compensated 3-Way Flow Control Valve (IL) block models constant-pressure flow control. When the control pressure,  $p_A - p_B$ , meets or exceeds the **Set orifice pressure differential**, the relief component of the underlying compensator valve opens to maintain the pressure in the block.

The flow control valve opening and closing is controlled by a physical signal received at port **S**, which determines the area of the underlying orifice block. A positive signal opens the valve. Port **R** vents liquid to another part of your network.

For pressure-compensated flow control without venting, see the Pressure-Compensated Flow Control Valve (IL) block.

## Orifice Parameterization

You can choose the valve model with the **Orifice parameterization** setting:

- **Linear - area vs. control member position** is an analytical formulation that assumes the valve opening area and the valve control member are related linearly.
- **Tabulated data - Area vs. control member position** is a user-supplied data sheet that relates orifice opening area and the control member position. The block queries between data points with linear interpolation and uses nearest extrapolation for points beyond the table boundaries.
- **Tabulated data - Volumetric flow rate vs. control member position and pressure drop** is a user-supplied data sheet that relates the control member position, orifice pressure drop, and orifice volumetric flow rate. The block queries between data points with linear interpolation and uses a nearest extrapolation for points beyond the table boundaries.

## Numerically-Smoothed Area and Pressure

When the orifice parameterization is linear, you can maintain numerical robustness at the extremes of the orifice area and valve pressure range by tuning the **Smoothing factor** parameter to a nonzero value less than 1. If the **Smoothing factor** parameter is nonzero, the block applies a smoothing function to all calculated areas and pressures, but it primarily influences the simulation at the extremes of these ranges.

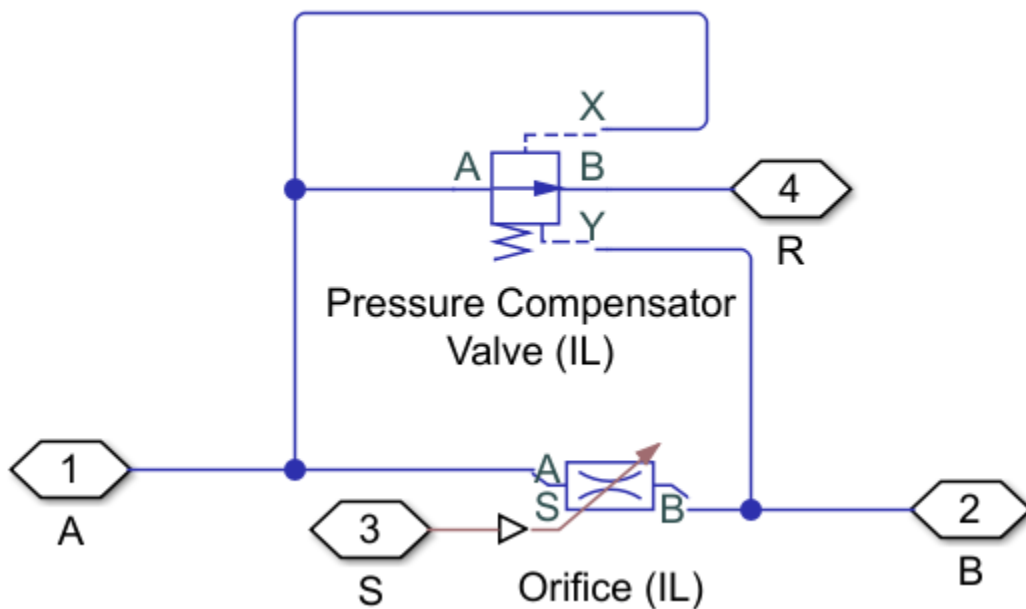
If you enable smoothing, the block smoothly saturates the orifice area between the **Leakage area** and **Maximum orifice area** parameters. The block smoothly saturates the valve pressure between

the **Set orifice pressure differential** parameter and the sum of the **Set orifice pressure differential** and the **Pressure compensator valve regulation range** parameters.

For more information, see “Numerical Smoothing”.

### Block Schematic

The Pressure-Compensated 3-Way Flow Control Valve (IL) is constructed from the Pressure Compensator Valve (IL) and Orifice (IL) blocks.



### Three-Way Flow Control Valve Schematic

#### Ports

##### Conserving

##### **A – Valve liquid port**

isothermal liquid

Liquid entry or exit port to the three-way valve.

##### **B – Orifice liquid port**

isothermal liquid

Liquid entry or exit port to the orifice.

##### **R – Reducing valve liquid port**

isothermal liquid

Liquid exit port from the reducing valve.



**Input****S — Physical signal, in m**

physical signal

Orifice opening in m, set as a physical signal.

**Parameters****Orifice parameterization — Method of modeling orifice opening**

Linear - area vs. control member position (default) | Tabulated data - Area vs. control member position | Tabulated data - Volumetric flow rate vs. control member position and pressure drop

Method of modeling the opening of the orifice. The opening is either parametrized linearly, which correlates the opening area to the control member position; by user-supplied data that correlate the orifice opening area to the control member position; or by an array of data that correlates the valve flow rate to the control member position and valve pressure drop.

**Control member position at closed orifice — Control member offset**

0 m (default) | scalar

Control member offset when the orifice is fully open. A positive, nonzero value indicates a partially closed orifice. A negative, nonzero value indicates an overlapped orifice that remains open for an initial displacement set by the physical signal at port S.

**Control member travel between closed and opened orifice — Maximum control member stroke**

5e-3 m (default) | positive scalar

Control member stroke that fully opens the orifice.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. control member position.

**Maximum orifice area — Maximum orifice cross-sectional area**8e-5 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice in its fully open position. This parameter is used as an upper limit for area-pressure calculations during the simulation.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. control member position.

**Control member position vector — Vector of opening position**

[0, .002, .007] m (default) | 1-by-n vector

Vector of orifice opening distances for the tabular parameterization of the orifice opening area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The elements are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Orifice area vector — Vector of opening areas**

[1e-09, 4e-09, 1e-05] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Control member position vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Control member position vector, *s* — Vector of control member positions**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member positions for the tabular parameterization of the volumetric flow rate. The control member position vector forms an independent axis with the **Pressure drop vector, *dp*** parameter for the 3-D dependent **Volumetric flow rate table, *q(s,dp)*** parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Pressure drop vector, *dp* — Vector of pressure differential values**

[.3, .5, .7] MPa (default) | 1-by-*n* vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The pressure drop vector forms an independent axis with the **Control member position vector, *s*** parameter for the 3-D dependent **Volumetric flow rate table, *q(s,dp)*** parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Volumetric flow rate table, *q(s,dp)* — Array of volumetric flow rate values**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) | *M*-by-*N* array

Array of volumetric flow rates based on independent values of pressure drop and spool travel distance. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of elements in the **Pressure drop vector, *dp*** parameter.
- *N* is the number of elements in the **Control member position vector, *s*** parameter.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

**Set orifice pressure differential – Threshold for compensator valve operation**

0.6 MPa (default) | positive scalar

Magnitude of pressure differential that triggers valve opening or closing.

**Pressure compensator valve regulation range – Area of the fully opened pressure compensator valve**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve in its fully open position. This parameter is used as an upper limit for area-pressure calculations during the simulation.

**Pressure compensator valve maximum area – Pressure operational region of the pressure compensating valve**

0.1 MPa (default) | scalar

Operational pressure range of the valve. The pressure regulation range lies between the **Set orifice pressure differential** and the maximum valve operating pressure.

**Leakage area – Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Version History**

Introduced in R2020a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Pressure-Compensated Flow Control Valve (IL) | Pressure Compensator Valve (IL) | Pressure-Reducing 3-Way Valve (IL) | Shuttle Valve (IL) | Orifice (IL)

# Pressure-Compensated Flow Control Valve

Hydraulic pressure compensating valve

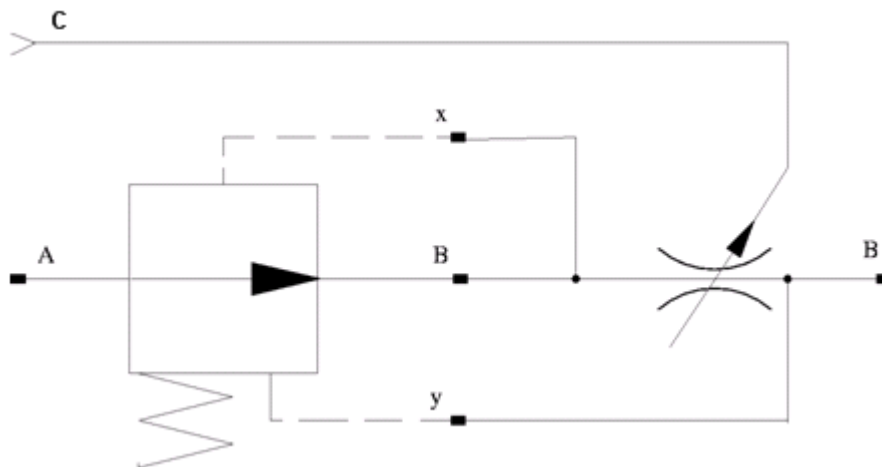


## Library

Flow Control Valves

## Description

The Pressure-Compensated Flow Control Valve block represents a pressure-compensated flow control valve as a data-sheet-based model. This flow control valve is composed of a Pressure Compensator valve block and a Variable Orifice block.



Depending on data listed in the manufacturer's catalogs or data sheets for your particular valve, you can choose one of the following model parameterization options:

- **By maximum area and opening** — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.
- **By area vs. opening table** — Use this option if the catalog or data sheet provides a table of the orifice passage area based on the control member displacement  $A=A(h)$ .

In the first case, the passage area is assumed to be linearly dependent on the control member displacement, that is, the orifice is assumed to be closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement.

The *valve maximum area* is 1.5x the maximum area of the orifice. This is the **Orifice maximum area** if the parameterization is **By maximum area and opening**, or the final element of the **Tabulated orifice area** if the parameterization is **By area vs. opening table**.

In the second case, the passage area is determined by one-dimensional interpolation from the table  $A=A(h)$ . In both cases, a small leakage area is assumed to exist even after the orifice is completely closed. Physically, it represents a possible clearance in the closed valve, but the main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause failure of computation.

The block positive direction is from port **A** to port **B**. This means that the flow rate is positive if it flows from **A** to **B**, and the pressure differential is determined as  $\Delta p = p_A - p_B$ . A positive signal at port **C** opens the valve.

## Assumptions and Limitations

Fluid inertia is not taken into account.

## Parameters

### Model parameterization

Select one of the following methods for specifying the orifice:

- By **maximum area and opening** — Provide values for the maximum orifice area and the maximum orifice opening. The passage area is linearly dependent on the control member displacement, that is, the orifice is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- By **area vs. opening table** — Provide tabulated data of orifice openings and corresponding orifice areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Orifice maximum area

Specify the area of a fully opened orifice. The parameter value must be greater than zero. The *valve maximum area* is 1.5x the **Orifice maximum area**. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Orifice maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-4 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Tabulated orifice openings

Specify the vector of input values for orifice openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-2e-3, 0, 5e-3, 15e-3]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**. **Tabulated orifice openings** values will be used together with **Tabulated orifice area** values for one-dimensional table lookup.

### Tabulated orifice area

Specify the vector of orifice areas as a one-dimensional array. The vector must be of the same size as the orifice openings vector. All the values must be positive. The *valve maximum area* is 1.5x the last element of the **Tabulated orifice area**. The default values, in  $\text{m}^2$ , are

[1e-12, 4e-12, 1.e-5, 1.02e-5]. This parameter is used if **Model parameterization** is set to By area vs. opening table.

### Interpolation method

This parameter is used if **Model parameterization** is set to By area vs. opening table. Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

### Extrapolation method

This parameter is used if **Model parameterization** is set to By area vs. opening table. Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page.

### Pressure differential across the orifice

Pressure difference that must be maintained across the element by the pressure compensator. The default value is 6e5 Pa.

### Pressure reducing valve regulation range

Pressure increase over the preset level needed to fully close the valve. Must be less than 0.2 of the **Pressure differential across the orifice** parameter value. The default value is 5e4 Pa.

### Flow discharge coefficient

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

### Initial opening

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to Pressure ratio.

**Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

**Leakage area**

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Interpolation method**
- **Extrapolation method**
- **Laminar transition specification**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

C

Physical signal control port.



## **Version History**

**Introduced in R2006a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Ball Valve | Gate Valve | Needle Valve | Poppet Valve

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Pressure-Compensated Flow Control Valve (IL)

Flow control with pressure regulation in an isothermal liquid system

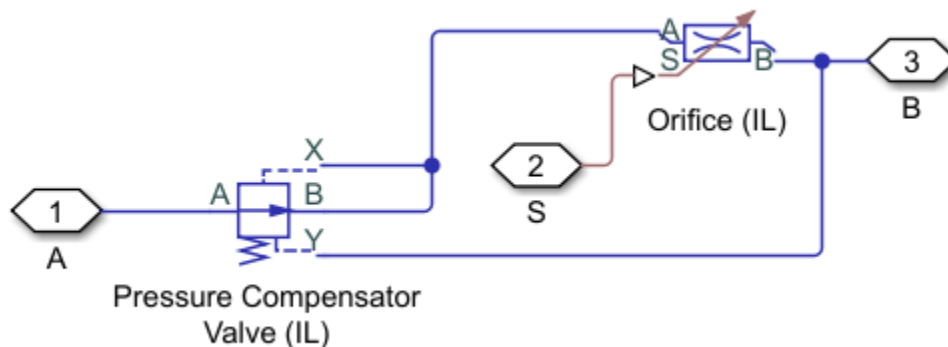
**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Flow Control Valves



### Description

The Pressure-Compensated Flow Control Valve (IL) block provides constant-pressure flow control through an Orifice (IL) block via a Pressure Compensator Valve (IL) connected in series. When the control pressure over the orifice,  $p_A - p_B$ , meets or exceeds the **Set orifice pressure differential**, the reducing valve in the pressure compensator component begins to close, which maintains the pressure in the orifice. For systems with venting or redirection of fluid to another part of the system, see the Pressure-Compensated 3-Way Flow Control Valve (IL) block.

The valve opening and closing is controlled by a physical signal received at port **S**. A positive signal opens the valve.



### Flow Control Valve Schematic

#### Numerically-Smoothed Area and Pressure

When the orifice parameterization is linear, you can maintain numerical robustness at the extremes of the orifice area and valve pressure range by tuning the **Smoothing factor** parameter to a nonzero value less than 1. If the **Smoothing factor** parameter is nonzero, the block applies a smoothing function to all calculated areas and pressures, but it primarily influences the simulation at the extremes of these ranges.

If you enable smoothing, the block smoothly saturates the orifice area between the **Leakage area** and **Maximum orifice area** parameters and applies a smoothing function. The block smoothly saturates the valve pressure between the **Set orifice pressure differential** parameter and the sum of the **Set orifice pressure differential** and the **Pressure compensator valve regulation range** parameters.

For more information, see “Numerical Smoothing”.

### Orifice Parameterization

Setting **Orifice parameterization** to:

- **Linear - area vs. control member position** assumes that the spool position and the orifice opening area are related linearly.
- **Tabulated data - Area vs. control member position** interpolates user-provided data between the orifice opening area and the control member position with a potentially nonlinear relationship.
- **Tabulated data - Volumetric flow rate vs. control member position and pressure drop** interpolates the orifice volumetric flow rate directly from user-provided data between the control member position, orifice pressure drop, and orifice volumetric flow rate.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit point to the valve.

#### B – Liquid port

isothermal liquid

Liquid entry or exit point to the valve.

### Input

#### S – Physical signal, in m

physical signal

Orifice opening in m, returned as a physical signal. A positive signal opens the orifice.

## Parameters

### Orifice parameterization – Method of modeling orifice opening

Linear - area vs. control member position (default) | Tabulated data - Area vs. control member position | Tabulated data - Volumetric flow rate vs. control member position and pressure drop

Method of modeling the opening of the orifice. The opening is either parametrized linearly, which correlates the opening area to the control member position; by user-supplied data that correlate the orifice opening area to the control member position; or by an array of data that correlates the valve flow rate to the control member position and valve pressure drop.

### Control member travel between closed and open valve – Maximum control member stroke

5e-3 m (default) | positive scalar

Control member stroke that fully opens the orifice.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. control member travel.

**Maximum orifice area — Maximum orifice cross-sectional area**

8e-5 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice in its fully open position. This parameter is used as an upper limit for area-pressure calculations during the simulation.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. control member travel.

**Control member position at closed valve — Control member offset**

0 m (default) | positive scalar

Control member offset when the orifice is fully open. A positive, nonzero value indicates a partially closed orifice. A negative, nonzero value indicates an overlapped orifice that remains open for an initial displacement set by the physical signal at port **S**.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Linear - area vs. control member travel.

**Control member position vector — Vector of control member travel distances**

[0, .002, .007] (default) | 1-by-*n* vector

Vector of orifice opening distances for the tabular parameterization of the orifice opening area. The vector elements must correspond one-to-one with the elements in the **Orifice area vector** parameter. The elements are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Orifice area vector — Vector of opening areas**

[1e-09, 4e-09, 1e-05] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Control member position vector** parameter. The elements are listed in ascending order and must be greater than 0.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Control member position vector, *s* — Vector of control member displacements**

[0, .002, .004, .007, .017] m (default) | 1-by-*n* vector

Vector of control member positions for the tabular parameterization of the volumetric flow rate. The control member position vector forms an independent axis with the **Pressure drop vector, *dp***

parameter for the 3-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

#### Pressure drop vector, $dp$ — Vector of pressure differential values

[.3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The pressure drop vector forms an independent axis with the **Control member position vector,  $s$**  parameter for the 3-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

#### Volumetric flow rate table, $q(s,dp)$ — Array of volumetric flow rate values

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13]  $\cdot 1e-3$  m<sup>3</sup>/s (default) |  $M$ -by- $N$  array

Array of volumetric flow rates based on independent values of pressure drop and spool travel distance.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Control member position vector,  $s$**  parameter.

#### Dependencies

To enable this parameter, set **Orifice parameterization** to Volumetric flow rate vs. control member position and pressure drop.

#### Set orifice pressure differential — Threshold for compensator valve operation

0.6 MPa (default) | scalar

Magnitude of pressure differential that triggers valve opening or closing.

#### Pressure compensator valve regulation range — Pressure operational region of the pressure compensating valve

0.1 MPa (default) | scalar

Operational pressure range of the valve. The pressure regulation range lies between the **Set orifice pressure differential** and the maximum valve operating pressure.

#### Pressure compensator valve maximum area — Area of the fully opened pressure compensator valve

$1.5 \cdot 8e-5$  m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve in its fully open position. This parameter is used as an upper limit for area-pressure calculations during the simulation.

**Leakage area — Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure Compensator Valve (IL) | Pressure-Reducing 3-Way Valve (IL) | Shuttle Valve (IL) | Orifice (IL)

# Pressure Compensator

Valve used to regulate the pressure drop across a hydraulic component

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Pressure Control Valves



## Description

The Pressure Compensator block models the flow through a valve that constricts so as to maintain a preset pressure drop between a chosen two hydraulic nodes. The valve has four hydraulic ports, two being flow passages (the inlet, **A**, and the outlet, **B**) and two pressure sensors (**X** and **Y**). The normally open valve contracts when the pressure drop from **X** to **Y** rises above the valve pressure setting. The drop in opening area is a function of the pressure drop—proportional to it in a linear parameterization (the block default) or a general function of it in a tabulated parameterization. The valve serves its purpose until it hits the limit of its pressure regulation range—a point at which the valve is fully closed and the pressure drop can again rise unabated.

## Valve Opening

The opening area calculation depends on the valve parameterization selected for the block: either Linear area-opening relationship or Tabulated data - Area vs. pressure.

### Linear Parameterization

If the **Valve parameterization** block parameter is in the default setting of Linear area-opening relationship, the opening area is computed as:

$$S(\Delta p_{xy}) = S_{\text{Max}} - k(\Delta p_{xy} - \Delta p_{\text{Set}}),$$

where:

- $S_{\text{Max}}$  is the value specified in the **Maximum passage area** block parameter.
- $\Delta p_{\text{Set}}$  is the value specified in the **Valve pressure setting** block parameter.
- $\Delta p_{XY}$  is the pressure drop from port **X** to port **Y**:

$$\Delta p_{XY} = p_X - p_Y,$$

where  $p$  is the gauge pressure at the port indicated by the subscript (**X** or **Y**).

- $k$  is the linear constant of proportionality:

$$k = \frac{S_{\text{Max}} - S_{\text{Leak}}}{\Delta p_{\text{Reg}}},$$

where in turn:

- $S_{\text{Leak}}$  is the value specified in the **Leakage area** block parameter.

- $\Delta p_{\text{Reg}}$  is that specified in the **Valve regulation range** block parameter.

At and below the valve pressure setting, the opening area is that of a fully open valve:

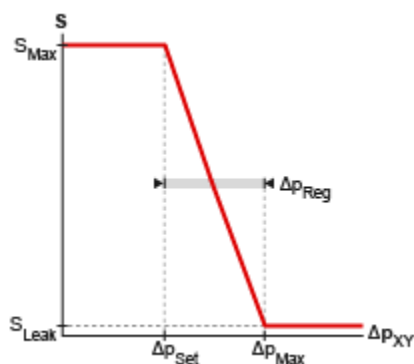
$$S(\Delta p_{XY} \leq \Delta p_{\text{Set}}) = S_{\text{Max}}.$$

At and above a maximum pressure, the opening area is that due to internal leakage alone:

$$S(\Delta p \geq \Delta p_{\text{Max}}) = S_{\text{Leak}},$$

where the maximum pressure drop  $\Delta p_{\text{Max}}$  is the sum:

$$\Delta p_{\text{Max}} = \Delta p_{\text{Set}} + \Delta p_{\text{Reg}}.$$



## Opening area in the Linear area-opening relationship parameterization

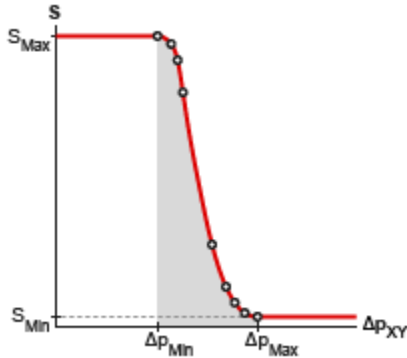
### Tabulated Parameterization

If the **Valve parameterization** block parameter is set to Tabulated data - Area vs. pressure, the opening area is computed as:

$$S = S(\Delta p_{XY}),$$

where  $S_{XY}$  is a tabulated function constructed from the **Pressure drop vector** and **Opening area vector** block parameters. The function is based on linear interpolation (for points within the data range) and nearest-neighbor extrapolation (for points outside the data range). The leakage and maximum opening areas are the minimum and maximum values of the **Valve opening area vector** block parameter.





## Opening area in the Tabulated data - Area vs. pressure parameterization

### Opening Dynamics

By default, the valve opening dynamics are ignored. The valve is assumed to respond instantaneously to changes in the pressure drop, without time lag between the onset of a pressure disturbance and the increased valve opening that the disturbance produces. If such time lags are of consequence in a model, you can capture them by setting the **Opening dynamics** block parameter to `Include valve opening dynamics`. The valves then open each at a rate given by the expression:

$$\dot{S} = \frac{S(\Delta p_{SS}) - S(\Delta p_{In})}{\tau},$$

where  $\tau$  is a measure of the time needed for the instantaneous opening area (subscript In) to reach a new steady-state value (subscript SS).

### Leakage Area

The primary purpose of the leakage area of a closed valve is to ensure that at no time does a portion of the hydraulic network become isolated from the remainder of the model. Such isolated portions reduce the numerical robustness of the model and can slow down simulation or cause it to fail. Leakage is generally present in minuscule amounts in real valves but in a model its exact value is less important than it being a small number greater than zero. The leakage area is obtained from the block parameter of the same name.

### Valve Flow Rate

The causes of the pressure losses incurred in the passages of the valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. This effect is captured in the block by the discharge coefficient, a measure of the flow rate through the valve relative to the theoretical value that it would have in an ideal valve. The flow rate through the valve is defined as:

$$q = C_D S \sqrt{\frac{2}{\rho} \frac{\Delta p_{AB}}{[(\Delta p_{AB})^2 + p_{Crit}^2]^{1/4}}},$$

where:

- $q$  is the volumetric flow rate through the valve.
- $C_D$  is the value of the **Discharge coefficient** block parameter.

- $S$  is the opening area of the valve.
- $\Delta p_{AB}$  is the pressure drop from port **A** to port **B**.
- $p_{\text{Crit}}$  is the pressure differential at which the flow shifts between the laminar and turbulent flow regimes.

The calculation of the critical pressure depends on the setting of the **Laminar transition specification** block parameter. If this parameter is in the default setting of By pressure ratio:

$$p_{\text{Crit}} = (p_{\text{Atm}} + p_{\text{Avg}})(1 - \beta_{\text{Crit}}),$$

where:

- $p_{\text{Atm}}$  is the atmospheric pressure (as defined for the corresponding hydraulic network).
- $p_{\text{Avg}}$  is the average of the gauge pressures at ports **A** and **B**.
- $\beta_{\text{Crit}}$  is the value of the **Laminar flow pressure ratio** block parameter.

If the **Laminar transition specification** block parameter is instead set to By Reynolds number:

$$p_{\text{Crit}} = \frac{\rho}{2} \left( \frac{Re_{\text{Crit}} \nu}{C_D D_H} \right)^2,$$

where:

- $Re_{\text{Crit}}$  is the value of the **Critical Reynolds number** block parameter.
- $\nu$  is the kinematic viscosity specified for the hydraulic network.
- $D_H$  is the instantaneous hydraulic diameter:

$$D_H = \sqrt{\frac{4S}{\pi}}.$$

## Ports

### Conserving

#### **A – Valve inlet**

hydraulic (isothermal liquid)

Opening through which the flow can enter the valve.

#### **B – Valve outlet**

hydraulic (isothermal liquid)

Opening through which the flow can exit the valve.

#### **X – Pressure sensor**

hydraulic (isothermal liquid)

Port at which pressure is measured for the purpose of setting the valve opening area.

#### **Y – Pressure sensor**

hydraulic (isothermal liquid)

Port at which pressure is measured for the purpose of setting the valve opening area.

## Parameters

### Opening area parameterization — Method by which to calculate the opening area of the valve

Linear area-opening relationship (default) | Tabulated data - Area vs. pressure

Method by which to calculate the opening area of the valve. The default setting prescribes a linear relationship between the opening area of the valve and the pressure drop between its sensor ports. The alternative setting allows for a general, nonlinear relationship to be specified in tabulated form.

### Maximum passage area — Opening area of the valve in the fully open position

$1e-4 \text{ m}^2$  (default) | positive scalar in units of area

Opening area of the valve in the fully open position. The valve is fully open if the pressure drop from port **X** to port **Y** is less than the value specified in the **Valve pressure setting** block parameter.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Valve pressure setting — Pressure drop to maintain from port X to port Y

$30e5 \text{ Pa}$  (default) | positive scalar in units of pressure

Pressure drop from port **X** to port **Y** that the valve is to maintain. The valve closes in proportion to the pressure drop if it should exceed the value specified here. If the pressure drop is less than this value, the opening area is that specified in the **Maximum passage area** block parameter.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Valve regulation range — Pressure drop interval over which the valve is to designed to operate

$1.5e5 \text{ Pa}$  (default) | positive scalar in units of pressure

Pressure drop interval over which the valve is designed to operate. This interval stretches from the largest pressure drop at which the valve is fully open to the lowest pressure drop at which the valve is fully closed. Only within this range is the valve capable of maintaining the specified pressure setting.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Discharge coefficient — Empirical factor defined as the ratio of actual to ideal mass flow rates

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter.

**Leakage area — Opening area of the valve in the maximally closed position**

$1e-10 \text{ m}^2$  (default) | positive scalar in units of area

Opening area of the valve in the fully closed position, when only internal leakage between its ports remains. This parameter serves primarily to ensure that closure of the valve does not cause portions of the thermal liquid network to become isolated. The exact value specified here is less important than its being a small number greater than zero.

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

**Pressure differential vector — Vector of pressure drops at which to tabulate the valve opening areas**

[30.15E5 : 15E3 : 31.35E5] Pa (default) | vector of positive numbers in units of pressure

Vector of pressure differentials from port **X** to port **Y** at which to specify the opening area of the valve. The vector elements must increase monotonically from left to right. This order is important when specifying the **Opening area vector** block parameter.

The block uses this data to construct a lookup table by which to determine from the pressure differential the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Opening area vector — Vector of opening areas at the specified pressure differential breakpoints**

[9E-5 : -1 : 1E-5]  $\text{m}^2$  (default) | vector of positive numbers in units of area

Vector of opening areas corresponding to the breakpoints defined in the **Pressure differential vector** block parameter. The vector elements must decrease monotonically from left to right (with increasing pressure). For best results, avoid regions of flattened slope.

The block uses this data to construct a lookup table by which to determine from the pressure differential the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Laminar transition specification — Parameter in terms of which to define the boundary between laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

Parameter in terms of which to specify the boundary between the laminar and turbulent flow regimes. The pressure ratio of the default parameterization is defined as the gauge pressure at the outlet divided by the same at the inlet.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | positive unitless scalar

Pressure ratio at which the flow is assumed to transition between laminar and turbulent regimes. The pressure ratio is defined as the gauge pressure at the outlet divided by the same at the inlet. The transition is assumed to be smooth and centered on this value.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Pressure ratio.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Reynolds number.

**Opening dynamics — Choice of whether to capture the opening dynamics of the valve**

Do not include valve opening dynamics (default) | Include valve opening dynamics

Choice of whether to capture the opening dynamics of the valve. Selecting Include valve opening dynamics causes the valve to open gradually, so as to approach its new steady-state area over a small time span. The characteristic time for such transitions is given in the **Opening time constant** block parameter.

Setting this parameter to the alternative Do not include valve opening dynamics is equivalent to specifying a value of 0 for the opening time constant. The opening area is in this case assumed to reach its new steady-state value instantaneously.

Include opening dynamics to more accurately capture the behavior of a real valve. For best real-time simulation performance, use with a local solver or disable valve opening dynamics altogether.

**Opening time constant — Characteristic time scale of the valve opening transitions**

0.1 s (default) | positive scalar in units of time

Measure of the time taken by the valve to transition from its current opening area to a new steady-state value. The block uses this parameter to calculate the rate at which a valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to Include valve opening dynamics.

**Initial area — Opening area at the start of simulation**1e-12 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow within the valve at the start of simulation. The block uses this parameter to calculate the initial rate at which the valve is opening and from it the instantaneous opening area at the next time step.

### **Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to Include valve opening dynamics.

## **Version History**

**Introduced in R2016a**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Pressure Reducing 3-Way Valve | Pressure Reducing Valve | Pressure Relief Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Pressure Compensator Valve (IL)

Pressure compensator valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Pressure Control Valves



## Description

The Pressure Compensator Valve (IL) block represents a pressure compensator in an isothermal liquid network, such as a pressure relief valve or pressure-reducing valve. Use this valve to maintain the pressure at the valve based on signals from another part of the system.

The pressure differential between ports **X** and **Y** is the control pressure,  $P_{control}$ . When this value meets or exceeds the set pressure, the valve area opens or closes depending on the **Valve specification** parameter. The pressure regulation range begins at the set pressure,  $P_{set}$ . You can choose between constant and controlled set pressure regulation. A physical signal at port **Ps** provides a varying set pressure.

## Pressure Control

The block regulates pressure when  $P_{control}$  exceeds  $P_{set}$ . The block continues to regulate the pressure up to  $P_{max}$ , the sum of  $P_{set}$  and the pressure regulation range. The block supports two modes of regulation:

- When you set **Set pressure control** to **Controlled** and connect a pressure signal to port **Ps**, the block keeps the pressure regulation range constant. The valve regulates pressure when  $P_{control}$  is greater than the value of the signal at port **Ps** and less than  $P_{max}$ .
- When you set **Set pressure control** to **Constant**, the **Set pressure differential** parameter defines a constant set pressure.

## Conservation of Mass

The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = 0.$$

The block calculates the mass flow rate through the valve as

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\rho}}{\sqrt{PR_{loss} \left( 1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 \right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient** parameter.
- $A_{valve}$  is the instantaneous valve open area.

- $A_{port}$  is the **Cross-sectional area at ports A and B** parameter.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential specified by the **Critical Reynolds number** parameter,  $Re_{crit}$ . This parameter represents the flow regime transition point between laminar and turbulent flow. The block finds the critical pressure difference as

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

The pressure loss,  $PR_{loss}$ , describes the reduction of pressure in the valve due to a decrease in area. The block calculates the pressure loss as:

$$PR_{loss} = \frac{\sqrt{1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}.$$

The pressure recovery describes the positive pressure change in the valve due to an increase in area. When you set **Pressure recovery** to **Off**, the block sets  $PR_{loss}$  to 1.

The block calculates  $A_{valve}$  using the opening parameterization and the valve opening dynamics.

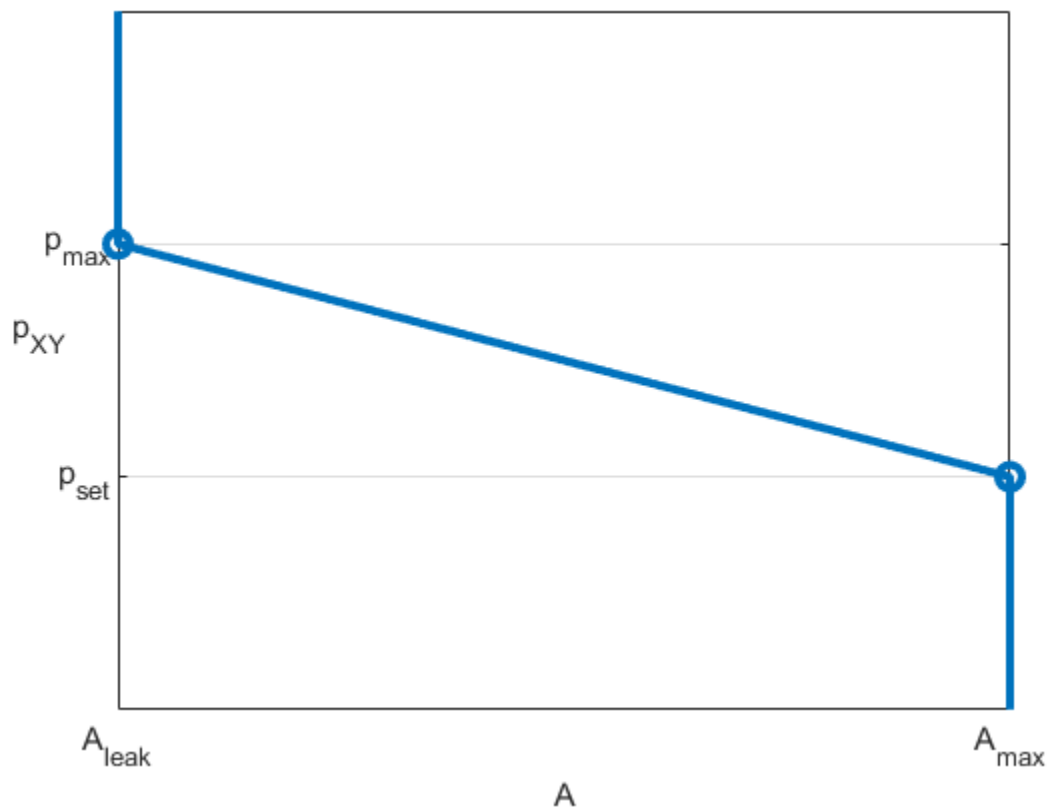
### Valve Opening Parameterization

When you set **Opening parameterization** to **Linear**, the valve area for normally open valves is

$$A_{valve} = \hat{p}(A_{leak} - A_{max}) + A_{max}.$$

This figure demonstrates how the block controls the opening area for a normally open valve using the linear parameterization.

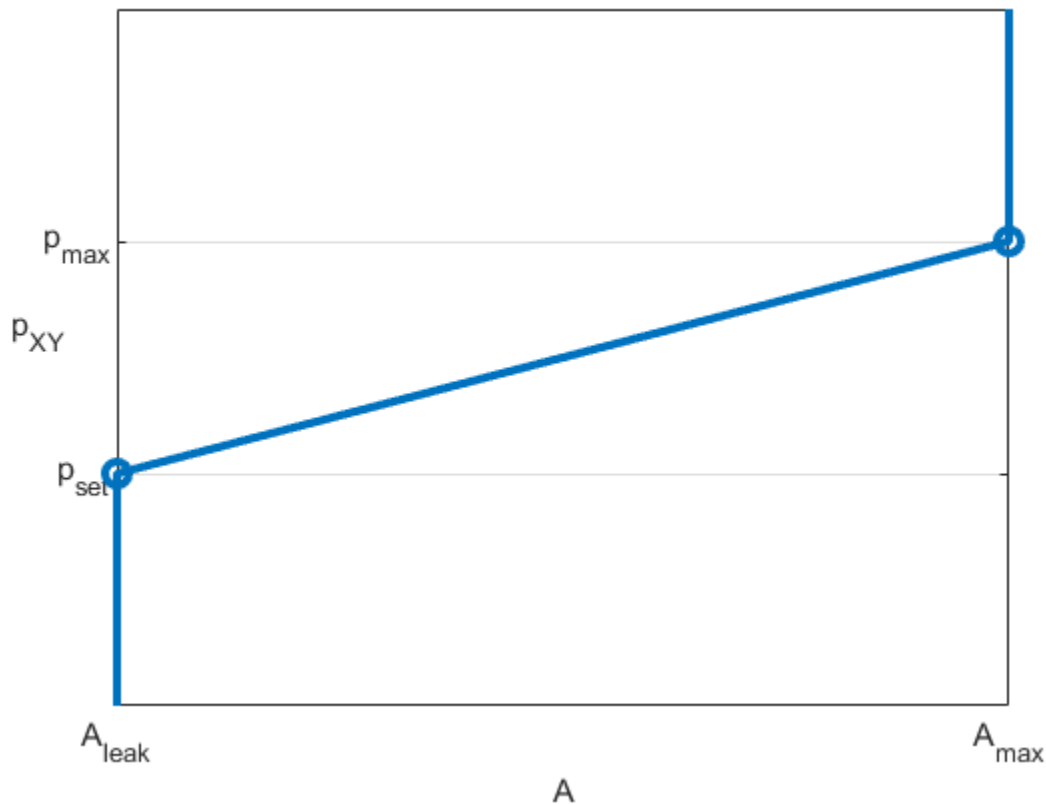




For normally closed valves, the block uses

$$A_{valve} = \hat{p}(A_{max} - A_{leak}) + A_{leak}.$$

This figure demonstrates how the block controls the opening area for a normally closed valve using the linear parameterization.



The normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{max} - p_{set}}.$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

When you set **Opening parameterization** to **Tabulated data**,  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Opening area vector** parameter, respectively. The block calculates the opening area as

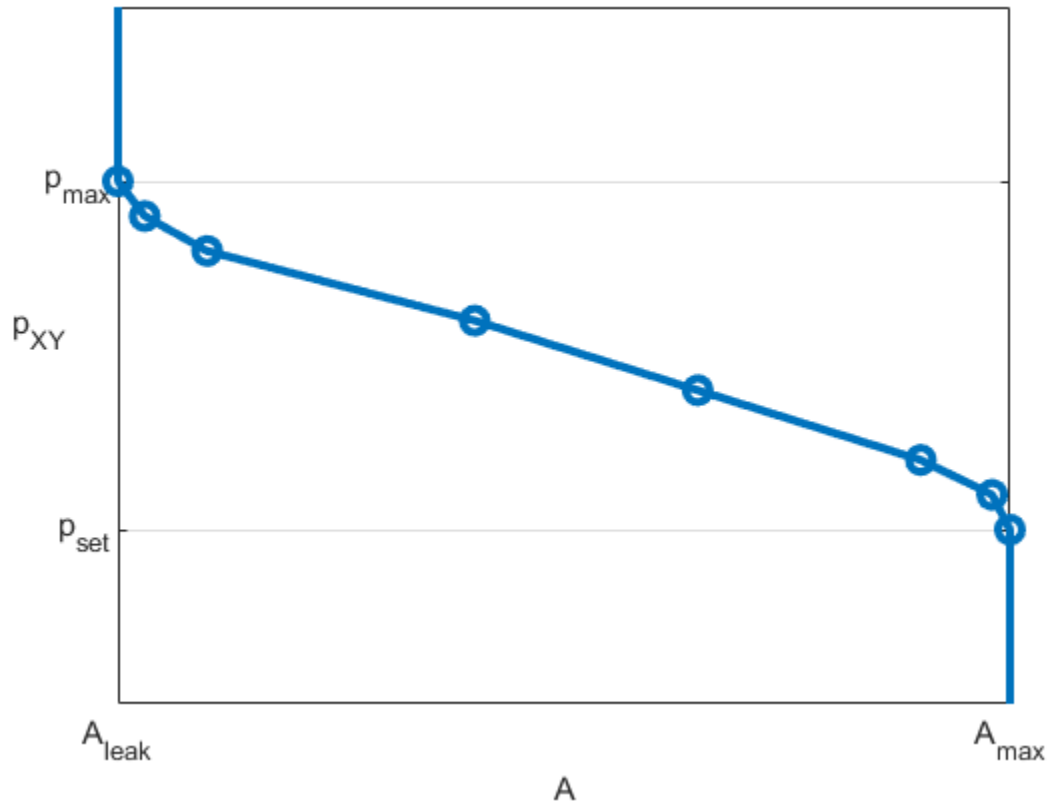
$$A_{valve} = \text{tablelookup}(p_{control, TLU, ref}, A_{TLU}, p_{control}, \text{interpolation} = \text{linear}, \text{extrapolation} = \text{nearest}),$$

where:

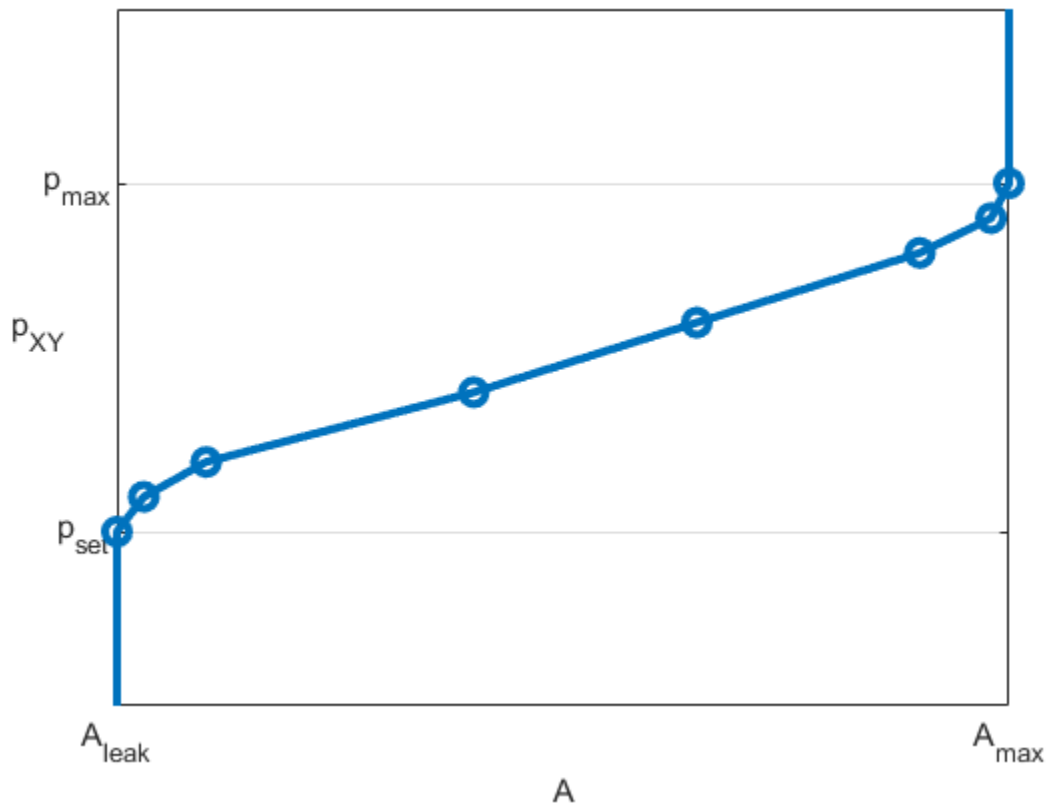
- $p_{control}$  is the control pressure, the pressure differential between ports **X** and **Y**.
- $p_{control, TLU, ref} = p_{TLU} + p_{offset}$ .
- $p_{TLU}$  is the **Pressure differential vector** parameter.
- $p_{offset}$  is an internal pressure offset that causes the valve to start closing when  $p_{control, TLU, ref} = p_{set}$ .

- $A_{TLU}$  is the **Opening area vector** parameter.

This figure demonstrates how the block controls the opening area for a normally open valve using the tabulated parameterization.



This figure demonstrates how the block controls the opening area for a normally closed valve using the tabulated parameterization.



### Opening Dynamics

When you set **Opening dynamics** to On, the block introduces a control pressure lag where  $p_{control}$  becomes the dynamic control pressure,  $p_{dyn}$ . The block calculates the instantaneous change in dynamic control pressure based on the **Opening time constant** parameter,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}$$

By default, **Opening dynamics** is Off. For the linear parameterization, a nonzero value for the **Smoothing factor** parameter provides additional numerical stability when the orifice is in near-closed or near-open position.

The block calculates the steady-state dynamics according to the **Opening parameterization** parameter, and are based on the control pressure,  $p_{control}$ .

### Faults

When you set **Enable faults** to On, the valve open area stops at a specified value in response to one of these triggers:

- Simulation time — The fault occurs at a specified time during the simulation.
- Simulation behavior — The fault occurs in response to an external trigger.

You can set the **Opening area when faulted** parameter to:

- **Closed** — The valve area stops at its smallest value, depending on the **Opening parameterization** parameter setting:
  - **Linear** — The valve area stops at the value of the **Leakage area** parameter.
  - **Tabulated data** — The valve area stops at the smallest element of the **Opening area vector** parameter.
- **Open** — The valve stops at its largest value, depending on the **Opening parameterization** parameter setting:
  - **Linear** — The valve area stops at the value of the **Maximum opening area** parameter.
  - **Tabulated data** — The valve area stops at the largest element of the **Opening area vector** parameter.
- **Maintain last value** — The valve area stops at the valve open area when the trigger occurred.

Due to numerical smoothing at the extremes of the valve area, the minimum area applied is larger than the leakage area, and the maximum is smaller than the value of the **Maximum orifice area** parameter. This effect is in proportion to the amount of smoothing you apply.

After the fault triggers, the valve remains at the faulted area for the rest of the simulation.

## Ports

### Conserving

#### **A — Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with the A side of the valve.

#### **B — Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with the B side of the valve.

#### **X — Pressure reference**

isothermal liquid

Isothermal liquid conserving port associated with sensing the pressure at point X,  $P_x$ .

#### **Y — Pressure reference**

isothermal liquid

Isothermal liquid conserving port associated with point Y,  $P_y$ .

### Input

#### **Ps — Controlled pressure differential, Pa**

physical signal

Pressure differential for controlled valve operation, in Pa.

**Dependencies**

To enable this port, set **Set pressure control** to `Controlled`.

**Tr — External fault trigger, unitless**

physical signal

Physical signal port for an external fault trigger, unitless. Triggering occurs when the value is greater than 0.5.

**Dependencies**

To enable this port, set **Enable faults** to `On` and **Fault trigger** to `External`.

**Parameters****Parameters****Valve specification — Valve bias**

Normally open (default) | Normally closed

Normal operating condition of the pressure compensator valve. For a reducing valve, choose `Normally open` valve. For a relief valve, choose `Normally closed`.

**Set pressure control — Constant or controlled valve operation**

Constant (default) | Controlled

Valve operation method. When you set this parameter to:

- `Controlled` and connect a pressure signal to port **Ps**, the block keeps the pressure regulation range constant. The valve regulates pressure when  $P_{control}$  is greater than the value of the signal at port **Ps** and less than  $P_{max}$ .
- `Constant`, the **Set pressure differential** parameter defines a constant set pressure.

**Opening parameterization — Opening parameterization**

Linear (default) | Tabulated data

Method to parameterize the opening action of the valve.

**Set pressure differential — Range outside of which constant valve operation is triggered**

0 MPa (default) | scalar

Magnitude of the pressure differential that triggers pressure compensation.

**Dependencies**

To enable this parameter, set **Set pressure control** to `Constant`.

**Pressure regulation range — Valve operational pressure range**

0.1 MPa (default) | scalar

Operational pressure range of the valve. The pressure regulation range defines the difference between the **Set pressure differential** parameter and the maximum valve operating pressure.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Maximum opening area — Area of fully open valve**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the valve in the fully open position.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Leakage area — Gap area when in fully closed position**

$1e-10 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value saturates to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Pressure differential vector — Differential pressure values for tabulated parameterization**

[0.2 : 0.2 : 1.2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabulated parameterization of the opening area. The vector elements must correspond one-to-one to the values in the **Opening area vector** parameter. The pressures must be in ascending order.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data.

**Opening area vector — Valve opening areas for tabulated parameterization**

[ $1e-05$ ,  $8e-06$ ,  $6e-06$ ,  $4e-06$ ,  $2e-06$ ,  $1e-10$ ]  $\text{m}^2$  (default) | 1-by-n vector

Vector of opening area values for the tabulated parameterization of the opening area. The vector elements must correspond one-to-one to the values in the **Pressure differential vector** parameter. For normally open valves, list elements in descending order. For normally closed valves, list elements in ascending order.

The opening area vector must have the same number of elements as the **Pressure differential vector**. The block uses linear interpolation between table data points.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data.

**Cross-sectional area at ports A and B — Area at valve entry or exit**

$\text{inf } \text{m}^2$  (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. The block uses this area in the pressure-flow rate equation that determines mass flow rate through the valve.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Pressure recovery — Option to include pressure recovery**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of a smaller cross-sectional area to a region of larger cross-sectional area.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range of [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Opening dynamics — Option to simulate flow response to valve transitions**

Off (default) | On

Whether to account for transient effects to the fluid system due to the valve opening. When you select On, the block approximates the opening conditions by introducing a first-order lag in the flow response.

**Opening time constant — Valve opening time constant**

0.1 s (default) | positive scalar

Time constant by which to compute the lag in the opening dynamics.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On.

**Faults****Enable faults — Fault option**

Off (default) | On

Whether to enable externally or temporally triggered faults. After a fault, the block sets the valve area to the value specified in the **Opening area when faulted** parameter.

**Opening area when faulted — Faulted valve position**

Closed (default) | Open | Maintain last value

Opening area that the valve assume following a fault. You can choose for the valve to seize when the valve is opened, closed, or at the area after a fault.



### Dependencies

To enable this parameter, set **Enable faults** to On.

### Fault trigger — External or temporal trigger option

Temporal (default) | External

Whether a fault trigger occurs due to an external event or at a specified time. When you select:

- **External** — The block enables port **Tr**. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.
- **Temporal** — When the simulation time reaches the value of the **Simulation time for fault event** parameter, the block sets the valve area according to the **Opening area when faulted** parameter.

### Dependencies

To enable this parameter, set **Enable faults** to On.

### Simulation time for fault event — Time at which fault triggers

5 s (default) | positive scalar

When the simulation time reaches the value of the **Simulation time for fault event** parameter, the block sets the valve area according to the **Opening area when faulted** parameter.

### Dependencies

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Pressure-Compensated Flow Control Valve (IL) | Pressure-Reducing 3-Way Valve (IL) | Pressure-Reducing Valve (IL) | Pressure Relief Valve (IL)

## Pressure Reducing 3-Way Valve

Composite valve comprising the functions of pressure reducing and relief valves

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Pressure Control Valves



### Description

The Pressure Reducing 3-Way Valve block models the flow through a valve that constricts and, if necessary, vents (via a separate line) so as to maintain a preset pressure differential between its outlet (port **A**) and its surroundings (**T**, the vent). The valve combines the functions of two more elementary valves, one a pressure-reducing valve, the other a pressure-relief valve.

The pressure-reducing valve runs between the inlet (**P**) and the outlet (**A**). It is normally open but closes as needed to combat pressure fluctuations upstream of the outlet. The pressure-relief valve runs between the outlet (**A**) and the vent (**T**). It is normally closed but opens if the outlet pressure should exceed (by a specified transition amount) the pressure regulation range of the pressure-reducing valve.

The valve opening areas are functions of the pressure differential from port **A** to port **T**—either directly proportional to it or general (tabulated) functions of it. The opening areas can each vary up to a point—the limit of the respective valve regulation range—beyond which the valve is saturated at full capacity and unable to counteract any additional pressure rises.

### Valve Opening

The opening area calculation depends on the valve parameterization selected for the block: either Linear area-opening relationship or Tabulated data - Area vs. pressure.

#### Linear Parameterization

If the **Valve parameterization** block parameter is in the default setting of Linear area-opening relationship, the opening area of the pressure-reducing valve (**P-A**) is computed as:

$$S_{PA} = \frac{S_{Max} + S_{Leak}}{2} - \frac{S_{Max} - S_{Leak}}{2} \tanh \left[ \frac{\lambda (\Delta p_{AT} - \Delta p_{Rdn})}{\Delta p_{Reg}/2} \right],$$

where the  $\tanh$  term serves to smooth the transitions to the fully open and fully closed valve positions. In the equation:

- $S_{Max}$  is the value specified in the **Maximum passage area** block parameter.
- $S_{Leak}$  is the value specified in the **Leakage area** block parameter.
- $\lambda$  is the value of the **Valve opening adjustment coefficient** block parameter, a measure of the smoothing to apply to the valve transitions. The smaller the value, the smoother the transition.
- $\Delta p_{Reg}$  is the value specified in the **Valve regulation range** block parameter.

- $\Delta p_{Rdn}$  is the midpoint of the pressure regulation range of the pressure-reducing valve:

$$\Delta p_{Rdn} = \Delta p_{Set} + \frac{\Delta p_{Reg}}{2},$$

with  $\Delta p_{Set}$  being the value of the **Reducing valve pressure setting** block parameter.

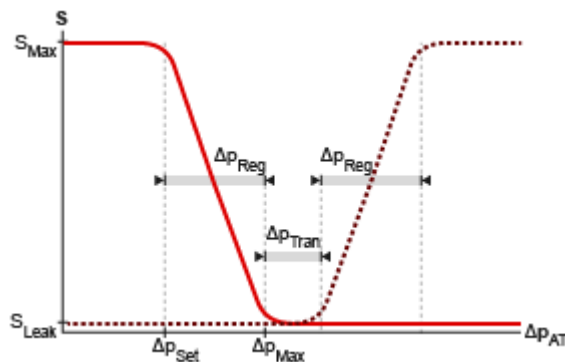
The opening area of the pressure-relief valve (**A-T**) is likewise computed as:

$$S_{AT} = \frac{S_{Max} + S_{Leak}}{2} + \frac{S_{Max} - S_{Leak}}{2} \tanh\left(\frac{\lambda(\Delta p_{AT} - \Delta p_{Rlf})}{\Delta p_{Reg}/2}\right),$$

where  $\Delta p_{Rlf}$  is the midpoint of the pressure regulation range of the pressure-relief valve:

$$\Delta p_{Rlf} = \Delta p_{Set} + \Delta p_{Reg} + \Delta p_{Tran} + \frac{\Delta p_{Reg}}{2},$$

with  $\Delta p_{Tran}$  being the transition pressure differential—that required for the pressure-relief valve to open after the pressure-reducing valve has fully closed. This value is obtained from the **Transition pressure** block parameter.



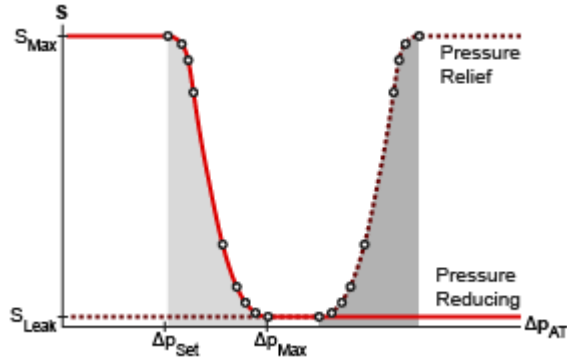
## Opening area in the Linear area-opening relationship parameterization

### Tabulated Parameterization

If the **Valve parameterization** block parameter is set to Tabulated data - Area vs. pressure, the valve opening areas are computed as:

$$S = S(\Delta p_{AT}),$$

where  $S_{AT}$  is a tabulated function constructed from the **Pressure drop vector** and **Opening area vector** block parameters. The function is based on linear interpolation (for points within the data range) and nearest-neighbor extrapolation (for points outside the data range). The leakage and maximum opening areas are the minimum and maximum values of the **Valve opening area vector** block parameter.



## Opening area in the Tabulated data - Area vs. pressure parameterization

### Opening Dynamics

By default, the valve opening dynamics are ignored. The valves are each assumed to respond instantaneously to changes in the pressure drop, without time lag between the onset of a pressure disturbance and the increased valve opening that the disturbance produces. If such time lags are of consequence in a model, you can capture them by setting the **Opening dynamics** block parameter to Include valve opening dynamics. The valves then open each at a rate given by the expression:

$$\dot{S} = \frac{S(\Delta p_{SS}) - S(\Delta p_{In})}{\tau},$$

where  $\tau$  is a measure of the time needed for the instantaneous opening area (subscript In) to reach a new steady-state value (subscript SS).

### Leakage Area

The primary purpose of the leakage area of a closed valve is to ensure that at no time does a portion of the hydraulic network become isolated from the remainder of the model. Such isolated portions reduce the numerical robustness of the model and can slow down simulation or cause it to fail. Leakage is generally present in minuscule amounts in real valves but in a model its exact value is less important than it being a small number greater than zero. The leakage area is obtained from the block parameter of the same name.

### Valve Flow Rates

The causes of the pressure losses incurred in the passages of the composite valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. This effect is captured in the block by the discharge coefficient, a measure of the flow rate through a valve relative to the theoretical value that it would have in the ideal case. The flow rates through each of the elementary valves are defined as:

$$q = C_D S \sqrt{\frac{2}{\rho} \frac{\Delta p}{[(\Delta p)^2 + p_{crit}^2]^{1/4}}},$$

where:

- $q$  is the volumetric flow rate through the valve (**P-A** or **A-T**).
- $C_D$  is the value of the **Discharge coefficient** block parameter.

- $S$  is the opening area of the valve ( $S_{PA}$  or  $S_{AT}$ ).
- $\Delta p$  is the pressure drop across the valve ( $\Delta p_{PA}$  or  $\Delta p_{AT}$ ).
- $p_{\text{Crit}}$  is the pressure differential at which the flow shifts between the laminar and turbulent flow regimes.

The calculation of the critical pressure depends on the setting of the **Laminar transition specification** block parameter. If this parameter is in the default setting of By pressure ratio:

$$p_{\text{Crit}} = (p_{\text{Atm}} + p_{\text{Avg}})(1 - \beta_{\text{Crit}}),$$

where:

- $p_{\text{Atm}}$  is the atmospheric pressure (as defined for the corresponding hydraulic network).
- $p_{\text{Avg}}$  is the average of the gauge pressures at the ports (**P** and **A** or **A** and **T**).
- $\beta_{\text{Crit}}$  is the value of the **Laminar flow pressure ratio** block parameter.

If the **Laminar transition specification** block parameter is instead set to By Reynolds number:

$$p_{\text{Crit}} = \frac{\rho}{2} \left( \frac{\text{Re}_{\text{Crit}} \nu}{C_D D_H} \right)^2,$$

where:

- $\text{Re}_{\text{Crit}}$  is the value of the **Critical Reynolds number** block parameter.
- $\nu$  is the kinematic viscosity specified for the hydraulic network.
- $D_H$  is the instantaneous hydraulic diameter:

$$D_H = \sqrt{\frac{4S}{\pi}}.$$

## Ports

### Conserving

#### **A – Valve outlet**

hydraulic (isothermal liquid)

Opening through which the flow can exit the valve.

#### **P – Valve inlet**

hydraulic (isothermal liquid)

Opening through which the flow can enter the valve.

#### **T – Valve vent**

hydraulic (isothermal liquid)

Opening through which the flow can vent from the valve.

## Parameters

### Opening area parameterization — Method by which to calculate the opening area of the valve

Linear area-opening relationship (default) | Tabulated data - Area vs. pressure

Method by which to calculate the opening area of the valve. The default setting prescribes a linear relationship between the opening area of the valve and the pressure drop between the outlet and the vent opening. The alternative setting allows for a general, nonlinear relationship to be specified in tabulated form.

### Maximum passage area — Opening areas of the P-A and A-T valves in the fully open position

$1e-4 \text{ m}^2$  (default) | positive scalar in units of area

Opening area of each valve when fully open. The pressure-reducing and pressure-relief valves are assumed to be identical in size. See the block description for the pressure conditions under which the valves can each be said to be fully open.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Reducing valve pressure setting — Pressure from port A to port T at which the reducing valve begins to close

$6e5 \text{ Pa}$  (default) | positive scalar in units of pressure

Pressure differential from port **A** to port **T** that the composite valve is to maintain. The pressure-reducing valve closes in proportion to the pressure differential if its value should exceed that specified here. The pressure-relief valve opens in proportion to the same if its value should exceed, by an amount given by the **Transition pressure** block parameter, that needed to fully close the reducing valve.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Valve regulation range — Pressure drop interval over which the valves are each designed to operate

$1.5e5 \text{ Pa}$  (default) | positive scalar in units of pressure

Pressure differential interval over which the valves are each designed to operate. This interval spans those pressures over which the opening area changes between its minimum and maximum values. The value specified here applies to both the pressure-reducing and pressure-relief valves.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Transition pressure — Pressure interval between the final closing of the reducing valve and the first opening of the relief valve

$2e5 \text{ Pa}$  (default) | positive scalar in units of pressure

Pressure differential in excess of that required to fully close the pressure-reducing valve at which the pressure-relief valve first opens. The greater the transition pressure, the greater the lag between the closing of the pressure-reducing valve and the opening of its pressure-relief counterpart.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### Valve flow discharge coefficient — Empirical factor defined as the ratio of actual to ideal mass flow rates

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter. The value specified here is shared by both pressure-reducing and pressure-relief valves.

#### Valve leakage area — Opening area of the valve in the maximally closed position

1e-10 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of a valve in the fully closed position, when only internal leakage between its respective ports remains. The leakage area is the same in the pressure-reducing and pressure-relief valves. This parameter serves primarily to ensure that closure of the valve does not cause portions of the hydraulic network to become isolated. The exact value specified here is less important than its being a small number greater than zero.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### Valve opening adjustment coefficient — Smoothing factor for easing the transition to the fully open or fully closed position

1 (default) | positive unitless scalar

Smoothing factor for easing the transition to the fully open or fully closed valve position. The smoothing enhances the numerical robustness of the model, helping to avoid numerical errors due to discontinuities and simulation slowdowns due to zero crossings. Use this parameter to scale the widths of the smoothed regions. The smaller the value, the broader the transition.

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### Pressure differential vector for reducing valve — Vector of pressure drops at which to tabulate the valve opening areas

[6.06E5 : .06E5 : 6.24E5] Pa (default) | vector of positive numbers in units of pressure

Vector of pressure drops from port **P** to port **A** at which to specify the opening area of the valve. The vector elements must increase monotonically from left to right. This order is important when specifying the **Opening area vector for reducing valve** block parameter.

The block uses this data to construct a lookup table by which to determine from the pressure differential the reducing-valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

#### Opening area vector for reducing valve – Vector of opening areas at the specified pressure differential breakpoints

[.9168, .69, .31, .0832] E-4 m<sup>2</sup> (default) | vector of positive numbers in units of area

Vector of opening areas corresponding to the breakpoints defined in the **Pressure differential vector for reducing valve** block parameter. The vector elements must decrease monotonically from left to right (with increasing pressure). For best results, avoid regions of flattened slope.

The block uses this data to construct a lookup table by which to determine from the pressure differential the reducing-valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

#### Pressure differential vector for relief valve – Vector of pressure drops at which to tabulate the valve opening areas

[6.2, 6.26, 6.32, 6.38] E5 Pa (default) | vector of positive numbers in units of pressure

Vector of pressure drops from port **A** to port **T** at which to specify the opening area of the valve. The vector elements must increase monotonically from left to right. This order is important when specifying the **Opening area vector for relief valve** block parameter.

The block uses this data to construct a lookup table by which to determine from the pressure differential the reducing-valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

#### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

#### Opening area vector for relief valve – Vector of opening areas at the specified pressure differential breakpoints

[.9168, .69, .31, .0832] E-4 m<sup>2</sup> (default) | vector of positive numbers in units of area

Vector of opening areas corresponding to the breakpoints defined in the **Pressure differential vector for relief valve** block parameter. The vector elements must decrease monotonically from left to right (with increasing pressure). For best results, avoid regions of flattened slope.

The block uses this data to construct a lookup table by which to determine from the pressure differential the reducing-valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).



**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Laminar transition specification — Parameter in terms of which to define the boundary between laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

Parameter in terms of which to specify the boundary between the laminar and turbulent flow regimes. The pressure ratio of the default parameterization is defined as the gauge pressure at the outlet divided by the same at the inlet.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | positive unitless scalar

Pressure ratio at which the flow is assumed to transition between laminar and turbulent regimes. The pressure ratio is defined as the gauge pressure at the outlet divided by the same at the inlet. The transition is assumed to be smooth and centered on this value.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Pressure ratio.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Reynolds number.

**Opening dynamics — Choice of whether to capture the opening dynamics of the valve**

Do not include valve opening dynamics (default) | Include valve opening dynamics

Choice of whether to capture the opening dynamics of the valve. Selecting **Include valve opening dynamics** causes the valve to open gradually, so as to approach its new steady-state area over a small time span. The characteristic time for such transitions is given in the **Opening time constant** block parameter.

Setting this parameter to the alternative **Do not include valve opening dynamics** is equivalent to specifying a value of 0 for the opening time constant. The opening area is in this case assumed to reach its new steady-state value instantaneously.

Include opening dynamics to more accurately capture the behavior of a real valve. For best real-time simulation performance, use with a local solver or disable valve opening dynamics altogether.

**Opening time constant — Characteristic time scale of the valve opening transitions**

0.1 s (default) | positive scalar in units of time

Measure of the time taken by the valve to transition from its current opening area to a new steady-state value. The block uses this parameter to calculate the rate at which a valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to Include valve opening dynamics.

**Initial reducing valve area — Opening area of the reducing valve at the start of simulation**

1e-9 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow within the pressure-reducing valve at the start of simulation. The block uses this parameter to calculate the initial rate at which the pressure-reducing valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to Include valve opening dynamics.

**Initial relief valve area — Opening area of the relief valve at the start of simulation**

1e-9 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow within the pressure-relief valve at the start of simulation. The block uses this parameter to calculate the initial rate at which the pressure-relief valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to Include valve opening dynamics.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure Compensator | Pressure Reducing Valve | Pressure Relief Valve

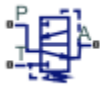
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Pressure-Reducing 3-Way Valve (IL)

Combined pressure-relief and pressure-reducing valve in isothermal system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Pressure Control Valves



## Description

The Pressure-Reducing 3-Way Valve (IL) is a combination of a pressure-relief and pressure-reducing valve. It maintains pressure at the valve outlet, port **A**, by restricting the inflow area at port **P** and venting the flow at port **T**.

## Valve Functionality

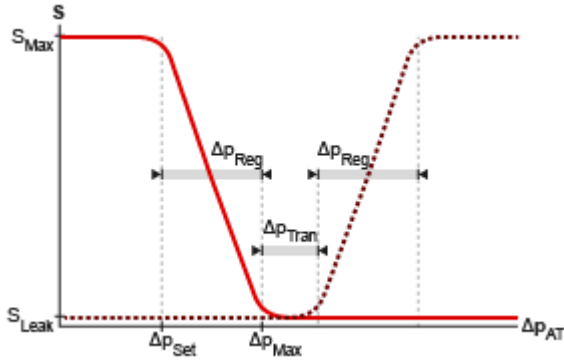
Valve operation is triggered by comparing the pressure difference between port **T** and port **A** to a threshold, the set pressure. When the pressure between **T** and **A**,  $P_{\text{control}}$ , exceeds this set pressure,  $P_{\text{set, reducing}}$ , port **P** begins to close. A transition pressure range defines the pressures the valve experiences when both valves at ports **P** and **T** are closed. When the pressure difference between ports **A** and **T** exceeds the pressure transition range, port **T** opens. That is,  $P_{\text{set, relief}} = P_{\text{set, reducing}} + P_{\text{range}} + P_{\text{transition}}$ . The **Pressure regulation range** is specified for both the pressure-reducing and the pressure-relief valves. The valve parameters, such as **Leakage Area** and **Maximum Opening Area**, are the same for all ports.

To simulate pressure relief or pressure reduction with respect to another system element, see Pressure Compensator Valve (IL). To simulate pressure reduction between the valve outlet and atmosphere, see the Pressure-Reducing Valve (IL). To simulate pressure relief with respect to a valve or between the valve outlet and atmospheric pressure, see Pressure Relief Valve (IL).

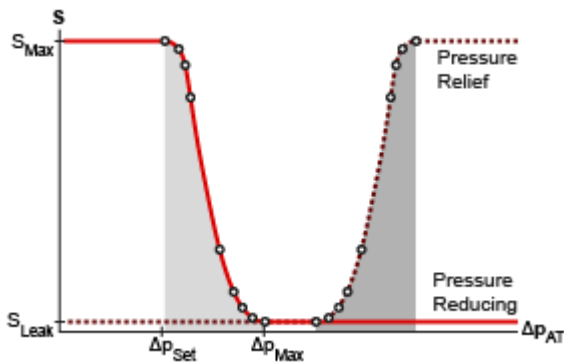
## Pressure Control

When  $P_{\text{control}}, P_A - P_T$ , exceeds the threshold pressure,  $P_{\text{set, reducing}}$ , the valve at port **P** begins to close. When the **Pressure transition range** is exceeded, or when  $P_{\text{control}} > P_{\text{set, relief}}$ , the valve at port **T** begins to open. Both valve closing and opening are parameterized in two ways:

- When **Set Pressure control** is set to **Controlled**, connect a pressure signal to port **Ps**, set the constant **Pressure regulation range**, and set the constant **Pressure transition range**. The pressure-reducing valve begins to close when  $P_{\text{control}}$  is greater than  $P_{\text{set, reducing}}$  and below  $P_{\text{max, reducing}}$ . The relief valve response is triggered when  $P_{\text{control}}$  is greater than  $P_{\text{set, relief}}$  and below  $P_{\text{max, relief}}$ .  $P_{\text{max, relief}}$  is the sum of the **Pressure regulation range** and  $P_{\text{set, relief}}$ .
- When **Set Pressure control** is set to **Constant**, valve closing at port **P** is continuously regulated by either a linear or tabular parameterization. Similarly, relief valve opening at port **T** is parameterized linearly or by table lookup. An example of linear parameterization of the reduction valve (solid line) and relief valve (dotted line) is shown below.



When the Tabulated data option is selected,  $P_{set, reducing}$  and  $P_{max, reducing}$  are the first and last parameters of the **Pressure differential vector for reducing valve**, respectively, and  $P_{set, relief}$  and  $P_{max, relief}$  are the first and last parameters of the **Pressure differential vector for relief valve**, respectively. An example of tabular parameterization of both the reducing and relieving valves are shown below.



### Mass Flow Rate Equation

Momentum is conserved through the valve:

$$\dot{m}_A + \dot{m}_{reducing} + \dot{m}_{relief} = 0.$$

The mass flow rate through the valves is calculated as:

$$\dot{m}_{reducing} = \frac{C_d A_{PA} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss, reducing} \left(1 - \left(\frac{A_{PA}}{A_{port}}\right)^2\right)}} \frac{\Delta p_{reducing}}{[\Delta p_{reducing}^2 + \Delta p_{crit, reducing}^2]^{1/4}},$$

$$\dot{m}_{relief} = \frac{C_d A_{AT} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss, relief} \left(1 - \left(\frac{A_{AT}}{A_{port}}\right)^2\right)}} \frac{\Delta p_{relief}}{[\Delta p_{relief}^2 + \Delta p_{crit, relief}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.

- $A$  is the instantaneous valve open area between ports **A** and **P** or **A** and **T**, as indicated by the subscript.
- $A_{port}$  is the **Cross-sectional area at ports A, P & T**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference:  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow, which corresponds to either the pressure-reducing or pressure relief component of the valve:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8A} \left( \frac{\nu Re_{crit}}{C_d} \right)^2,$$

where  $A$  is either  $A_{PA}$  or  $A_{AT}$ , corresponding to the reducing or relief component of the valve, respectively.

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A}{A_{port}}}{\sqrt{1 - \left(\frac{A}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

The opening area  $A$  is determined by the opening parameterization (for Constant valves only) of the reducing valve (**P** to **A**) or relief valve (**A** to **T**) and the valve opening dynamics.

### Opening and Closing Parameterization

Linear parameterization of the valve area for the reducing valve is

$$A_{valve} = \hat{p}_{reducing}(A_{leak} - A_{max}) + A_{max},$$

and for the relief valve is

$$A_{valve} = \hat{p}_{relief}(A_{max} - A_{leak}) + A_{leak}.$$

The normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{max} - p_{set}},$$

where the set and maximum pressures are the respective reducing or relief valve settings.

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

In the Tabulated data parameterization,  $A_{leak,PA}$  and  $A_{max,PA}$  are the first and last parameters of the **Opening area vector reducing valve**, respectively, and  $A_{leak,AT}$  and  $A_{max,AT}$  are the first and last parameters of the **Opening area vector for relief valve**, respectively.

### Opening Dynamics

If **Opening dynamics** are modeled, a lag is introduced to the flow response to valve opening.  $A_{valve}$  becomes the dynamic opening or closing area,  $A_{dyn}$ ; otherwise,  $A_{valve}$  is the steady-state opening area. This area is specific to the reducing and relief components of the valve,  $A_{PA}$  or  $A_{AT}$ , respectively. The instantaneous change in dynamic opening area is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, **Opening dynamics** is set to Off.

### Faults

When faults are enabled, the reducing and relief valve open areas become stuck at a specified value in response to one of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **Tr**.

Three fault options are available in the **Valve areas when faulted** parameter:

- Reducing valve closed and relief valve open — The reducing valve freezes at its smallest value and the relief valve freezes at its largest value, depending on the **Opening parameterization**:
  - When **Opening parameterization** is set to **Linear**, the reducing valve area freezes at the **Leakage area** and the relief valve area freezes at the **Maximum opening area**.
  - When **Opening parameterization** is set to **Tabulated data**, the reducing valve area freezes at the first element of the **Opening area vector** and the relief valve area freezes at the last element of the **Opening area vector**.
- Reducing valve open and relief valve closed — The reducing valve freezes at its largest value and the relief valve freezes at its smallest value, depending on the **Opening parameterization**:
  - When **Opening parameterization** is set to **Linear**, the reducing valve area freezes at the **Maximum opening area** and the relief valve freezes at the **Leakage area**.
  - When **Orifice parameterization** is set to **Tabulated data**, the reducing valve area freezes at the last element of the **Opening area vector** and the relief valve area freezes at the first element of the **Opening area vector**.
- Maintain last value — The reducing and relief valve areas freeze at the open area when the trigger occurred.

Due to numerical smoothing at the extremes of the valve area, the minimum area applied is larger than the **Leakage area**, and the maximum is smaller than the **Maximum orifice area**, in proportion to the **Smoothing factor** value.

Once triggered, the valves remain at the faulted area for the rest of the simulation.

## Assumptions and Limitations

Friction between the valve and fluid, the hydraulic force of the fluid on the valve components, and the effect of fluid inertia are neglected.

## Port

### Conserving

#### A — Liquid port

isothermal liquid

Liquid exit port of the valve.

#### P — Liquid port

isothermal liquid

Liquid entry port to the valve.

#### T — Liquid port

isothermal liquid

Liquid relief port of the valve.

## Input

#### Ps — Controlled pressure differential

physical signal

Varying-signal set pressure for controlled valve operation.

### Dependencies

To enable this port, set **Set pressure control** to **Controlled**.

#### Tr — External fault trigger

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

### Dependencies

This port is visible when **Enable faults** is set to **On** and **Fault trigger** is set to **External**.

## Parameters

### Parameters

#### Set pressure control — Valve operation method

Constant (default) | Controlled

Valve operation method. A **Constant** valve opens or closes linearly over a fixed pressure regulation range and pressure transition or in accordance with tabulated pressure and opening area data that you provide. A **Controlled** valve opens or closes according to a variable set pressure signal at port

**Pset** over a fixed pressure regulation and pressure transition range. The selected setting applies both to the reducing and relief valve operation.

### **Opening parameterization — Type of opening parameterization**

Linear (default) | Tabulated data

Method of modeling the valve opening or closing. Valve opening is either parametrized linearly, which correlates the opening area to the provided pressure range, or by a table of values you provide that correlate the valve opening area to pressure differential data.

#### **Dependencies**

To enable this port, set **Set pressure control** to Constant.

### **Set pressure differential for reducing valve — Set pressure for valve closing at port P**

0.6 MPa (default) | scalar

Pressure differential between port **T** and port **A**. When this set pressure differential is surpassed, the valve at port **P** begins to close. The closing is parametrized linearly or by lookup table as defined in the **Opening parameterization**.

### **Pressure regulation range — Valve operational pressure range**

3e-2 MPa (default) | scalar

Operational pressure range of the reducing valve. The pressure regulation range lies between the **Set pressure differential** and the maximum valve operating pressure. At the end of the **Pressure regulation range**, the pressure-reducing valve is closed and the **Pressure transition range** begins.

#### **Dependencies**

To enable this parameter, set

- **Set pressure control** to Controlled, or
- **Set pressure control** to Constant and **Opening parameterization** to Linear.

### **Pressure transition range — Pressure range of valve with ports P and T closed**

2e-2 MPa (default) | scalar

Pressure range of the 3-way valve. This parameter defines the pressure range, which begins at the end of the **Pressure regulation range**, over which both ports **P** and **T** are closed. Below this range, the reducing valve at port **P** is open to flow, and above this range, the relief valve at port **T** opens.

#### **Dependencies**

To enable this parameter, set either:

- **Set pressure control** to Controlled
- **Set pressure control** to Constant and **Opening parameterization** to Linear

### **Maximum opening area — Maximum opening area of ports**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve (**P-A** or **A-T**) in its fully-open position.



**Dependencies**

To enable this parameter, set either:

- **Set pressure control** to Controlled
- **Set pressure control** to Constant and **Opening parameterization** to Linear

**Leakage area – Gap area when in fully closed position**

$1e-10 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the valve is in fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set either:

- **Set pressure control** to Controlled
- **Set pressure control** to Constant and **Opening parameterization** to Linear

**Pressure differential vector for reducing valve – Differential pressure values for tabular parameterization of reducing valve**

0.6 : 0.02 : 0.7 MPa (default) | 1-by- $n$  vector

Vector of pressure differential values for the tabular parameterization of opening area. The vector elements correspond one-to-one to the values in the **Opening area vector reducing valve** parameter. Pressure differential vector values are listed in ascending order and must have the same number of elements as the **Opening area vector reducing valve** parameter. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data.

**Opening area vector reducing valve – Vector of valve opening areas for tabular parameterization of reducing valve**

$[1e-05, 8e-06, 6e-06, 4e-06, 2e-06, 1e-10] \text{ m}^2$  (default) | 1-by- $n$  vector

Vector of opening area values for the tabular parameterization of opening area. The vector elements must correspond one-to-one to the values in the **Pressure differential vector for reducing valve** parameter. Areas are listed in descending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data.

**Pressure differential vector for relief valve – Differential pressure values for tabular parameterization of relief valve**

0.68 : 0.02 : 0.78 MPa (default) | 1-by- $n$  vector

Vector of pressure differential values for the tabular parameterization of opening area. The vector elements correspond one-to-one to the values in the **Opening area vector relief valve** parameter.

Pressure differential vector values are listed in ascending order and must have the same number of elements as the **Opening area vector relief valve** parameter. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data.

**Opening area vector for relief valve – Valve opening areas for tabular parameterization of relief valve**

[1e-10, 2e-06, 4e-06, 6e-06, 8e-06, 1e-05] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening area values for the tabular parameterization of opening area. The vector elements must correspond one-to-one to the values in the **Pressure differential vector for relief valve** parameter. Areas are listed in ascending order. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data.

**Cross-sectional area at ports A, P & T. – Orifice area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A**, **P**, and **T**. This area is used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows. The default discharge coefficient for a valve in Simscape Fluids is 0.64.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range of [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Pressure recovery – Whether to account for pressure increase in area expansions**

Off (default) | On

Accounts for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area. This increase in pressure is not captured when **Pressure recovery** is set to Off.

**Opening dynamics – Whether to introduce flow lag due to orifice opening**

Off (default) | On

Accounts for transient effects to the fluid system due to the valve opening. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the flow response. The **Opening time constant** also impacts the modeled opening dynamics.

**Reducing valve initial opening area – Open area at port P at the start of the simulation**1e-4 m<sup>2</sup> (default) | positive scalar

Initial cross-sectional area at port **P** at the time of dynamic opening. This value is used to calculate the instantaneous opening area for the dynamic opening between **P** and **A** at the following time step.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On.

**Relief valve initial opening area – Open area at port T at the start of the simulation**1e-10 m<sup>2</sup> (default) | positive scalar

Initial cross-sectional area at port **T** of opening at the time of dynamic opening. This value is used to calculate the instantaneous opening area for the dynamic opening between **A** and **T** at the following time step.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On.

**Opening time constant – Valve opening time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On.

**Faults****Enable faults – Fault option**

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Opening area when faulted** parameter.

**Valve areas when faulted – Set faulted characteristics**

Reducing valve closed and relief valve open (default) | Reducing valve open and relief valve closed | Maintain last value

Sets the faulted valve type. You can choose for the valve to seize when the valves are opened, closed, or at the area when faulting is triggered.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Fault trigger – External or temporal trigger option**

Temporal (default) | External

Whether a fault trigger occurs due to an external event or at a specified time.

When set to External, port **Tr** is enabled. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.

When set to Temporal, when the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Simulation time for fault event – Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure Compensator Valve (IL) | Pressure-Reducing Valve (IL) | Pressure Relief Valve (IL) | Counterbalance Valve (IL)

# Pressure Reducing Valve

Valve used to reduce pressure to a specified value

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Pressure Control Valves

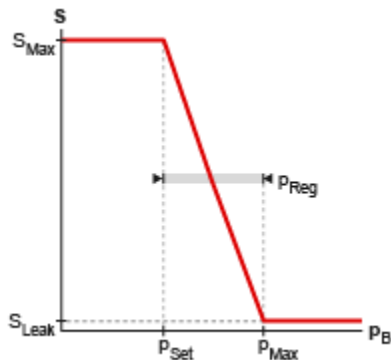


## Description

The Pressure Reducing Valve block models the flow through a valve that constricts so as to maintain a preset gauge pressure at its outlet (port **B**). The normally open valve contracts when the outlet pressure, measured against atmospheric pressure, exceeds the valve pressure setting. The drop in opening area is a function of the outlet pressure—proportional to it in a linear parameterization (the block default) or a general function of it in a tabulated parameterization. The valve serves its purpose until it hits the limit of its pressure regulation range—a point at which the valve is fully closed and the outlet pressure can again rise unabated.

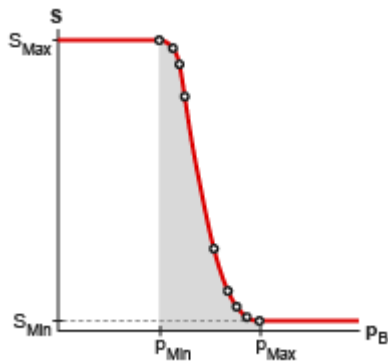
## Valve Opening

The figures show the opening characteristics of the valve. In the default valve parameterization, the opening area ( $S$ ) drops linearly with the outlet pressure ( $p_B$ ) with its value ranging from a maximum in the fully open position ( $S_{Max}$ ) to a minimum in the fully closed position ( $S_{Leak}$ ). The drop occurs over a pressure range stretching from the valve pressure setting ( $p_{Set}$ ) to a maximum equal to the sum of the valve regulation range ( $p_{Reg}$ ) and the valve pressure setting.



## Opening area in the Linear area-opening relationship parameterization

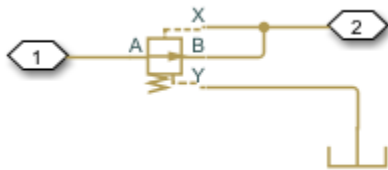
In the optional tabulated parameterization, the opening area is a general function of the outlet pressure, with its value dropping from a maximum ( $S_{Max}$ ) to a minimum ( $S_{Min}$ ) contained in the tabulated data. The maximum opening occurs at the minimum pressure ( $p_{Min}$ ) contained in the data and the minimum opening at the maximum pressure ( $p_{Max}$ ). Calculations are based on linear interpolation (between the tabulated bounds) and nearest-neighbor extrapolation (outside of those bounds).



## Opening area in the Tabulated data - Area vs. pressure parameterization

### Composite Diagram

This block is a composite component with a Pressure Compensator block connected as follows: its sensor port **X** connected to its outlet (port **B**) and its sensor port **Y** connected to a hydraulic reference. The hydraulic reference is by definition at atmospheric pressure as defined for the entire hydraulic network. For detailed block calculations see the Pressure Compensator block (noting that quantities at port **X** are defined at port **B** and those at port **Y** are defined at reference conditions).



### Composite model of the pressure relief valve

## Ports

### Conserving

#### A – Valve inlet

hydraulic (isothermal liquid)

Opening through which the flow can enter the valve.

#### B – Valve outlet

hydraulic (isothermal liquid)

Opening through which the flow can exit the valve.

## Parameters

### Opening area parameterization – Method by which to calculate the opening area of the valve

Linear area-opening relationship (default) | Tabulated data - Area vs. pressure

Method by which to calculate the opening area of the valve. The default setting prescribes a linear relationship between the opening area of the valve and the pressure drop between its sensor ports. The alternative setting allows for a general, nonlinear relationship to be specified in tabulated form.

#### **Maximum passage area — Opening area of the valve in the fully open position**

1e-4 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully open position. The valve is fully open if the pressure at port **B** relative to a hydraulic reference at atmospheric pressure is less than the value specified in the **Valve pressure setting** block parameter.

#### **Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### **Valve pressure setting — Pressure drop to maintain at port B relative to a hydraulic reference**

30e5 Pa (default) | positive scalar in units of pressure

Gauge pressure that the valve is to maintain at port **B**. The valve closes in proportion to the gauge pressure if it should exceed the value specified here. If the pressure drop is less than this value, the opening area is that specified in the **Maximum passage area** block parameter.

#### **Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### **Valve regulation range — Pressure interval over which the valve is designed to operate**

1.5e5 Pa (default) | positive scalar in units of pressure

Pressure interval over which the valve is designed to operate. This interval stretches from the largest pressure at which the valve is fully open to the lowest pressure at which the valve is fully closed. Only within this range is the valve capable of maintaining the specified pressure setting.

#### **Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

#### **Discharge coefficient — Empirical factor defined as the ratio of actual to ideal mass flow rates**

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter.

#### **Leakage area — Opening area of the valve in the maximally closed position**

1e-10 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully closed position, when only internal leakage between its ports remains. This parameter serves primarily to ensure that closure of the valve does not cause portions of the thermal liquid network to become isolated. The exact value specified here is less important than its being a small number greater than zero.

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

**Pressure differential vector — Vector of pressure drops at which to tabulate the valve opening areas**

[30.15E5 : 15E3 : 31.35E5] Pa (default) | vector of positive numbers in units of pressure

Vector of gauge pressures at port **B** at which to specify the opening area of the valve. The vector elements must increase monotonically from left to right. This order is important when specifying the **Opening area vector** block parameter.

The block uses this data to construct a lookup table by which to determine from the gauge pressure at port **B** the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Opening area vector — Vector of opening areas at the specified pressure differential breakpoints**

[9E-5 : -1 : 1E-5] m<sup>2</sup> (default) | vector of positive numbers in units of area

Vector of opening areas corresponding to the breakpoints defined in the **Pressure differential vector** block parameter. The vector elements must decrease monotonically from left to right (with increasing pressure). For best results, avoid regions of flattened slope.

The block uses this data to construct a lookup table by which to determine from the gauge pressure at port **B** the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Laminar transition specification — Parameter in terms of which to define the boundary between laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

Parameter in terms of which to specify the boundary between the laminar and turbulent flow regimes. The pressure ratio of the default parameterization is defined as the gauge pressure at the outlet divided by the same at the inlet.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | positive unitless scalar

Pressure ratio at which the flow is assumed to transition between laminar and turbulent regimes. The pressure ratio is defined as the gauge pressure at the outlet divided by the same at the inlet. The transition is assumed to be smooth and centered on this value.



**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to `Pressure ratio`.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to `Reynolds number`.

**Opening dynamics — Choice of whether to capture the opening dynamics of the valve**

`Do not include valve opening dynamics (default)` | `Include valve opening dynamics`

Choice of whether to capture the opening dynamics of the valve. Selecting `Include valve opening dynamics` causes the valve to open gradually, so as to approach its new steady-state area over a small time span. The characteristic time for such transitions is given in the **Opening time constant** block parameter.

Setting this parameter to the alternative `Do not include valve opening dynamics` is equivalent to specifying a value of 0 for the opening time constant. The opening area is in this case assumed to reach its new steady-state value instantaneously.

Include opening dynamics to more accurately capture the behavior of a real valve. For best real-time simulation performance, use with a local solver or disable valve opening dynamics altogether.

**Opening time constant — Characteristic time scale of the valve opening transitions**

0.1 s (default) | positive scalar in units of time

Measure of the time taken by the valve to transition from its current opening area to a new steady-state value. The block uses this parameter to calculate the rate at which a valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to `Include valve opening dynamics`.

**Initial area — Opening area at the start of simulation**

1e-12 m<sup>2</sup> (default) | positive scalar in units of area

Area normal to the direction of flow within the valve at the start of simulation. The block uses this parameter to calculate the initial rate at which the valve is opening and from it the instantaneous opening area at the next time step.

**Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to `Include valve opening dynamics`.

## **Version History**

**Introduced in R2016a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Pressure Compensator | Pressure Reducing 3-Way Valve | Pressure Relief Valve

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Pressure-Reducing Valve (IL)

Pressure-reducing valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Pressure Control Valves



## Description

The Pressure-Reducing Valve (IL) block represents a pressure-reducing valve in an isothermal liquid network. The valve remains open when the pressure at port **B** is less than a specified pressure. When the pressure at port **B** meets or surpasses this pressure, the valve closes. The block operates based on the differential between the set pressure and the pressure at port **B**. The block contains a check valve portion that functions identically to the Check Valve (IL) block during flow reversals. For pressure control based on another location in the fluid network, see the Pressure Compensator Valve (IL) block.

### Set Pressure Control

The block regulates pressure between the set pressure and maximum pressure. When you set **Set pressure control** to:

- **Controlled** — You can connect a pressure signal to port **Ps**. The block regulates pressure when the pressure at port **B** is greater than the reference set pressure,  $P_{set}$ , and below  $P_{max}$ . The pressure at port **B** acts as the control pressure,  $P_{control}$ , for this valve.

$P_{max}$  is the sum of  $P_{set}$  and the pressure regulation range.

- **Constant** — The **Set pressure (gauge)** parameter defines a constant set pressure.

How the block determines the pressure regulation range depends on the **Opening parameterization** parameter:

- **Linear - Area vs. pressure** — The **Pressure regulation range** parameter defines the pressure regulation range.
- **Tabulated data - Area vs. Pressure** — The pressure regulation range is the difference between the last and first elements of the **Port B (gauge) vector** parameter.
- **Tabulated data - Volumetric flow rate vs. pressure** — The pressure regulation range is the difference between the first and last elements of the **Reference pressure at port B (gauge) vector** parameter.

### Area vs. Pressure Parameterizations

When you set **Opening parameterization** to **Linear - Area vs. pressure**, the block calculates the valve area as

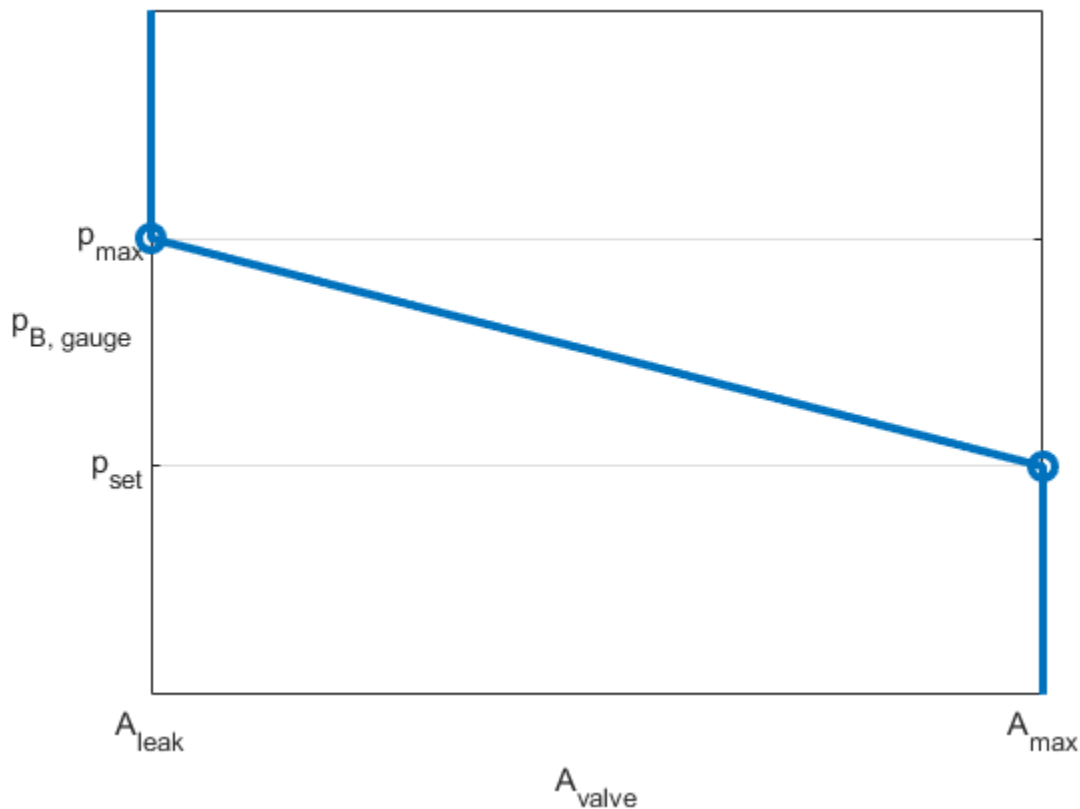
$$A_{valve} = \hat{p}(A_{leak} - A_{max}) + A_{max}$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{max} - p_{set}}.$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

The figure demonstrates the opening characteristics of the valve when using the linear area parameterization. The opening area,  $A_{valve}$ , drops linearly with the outlet pressure,  $p_{B,gauge}$ . The opening area ranges from  $A_{leak}$  to  $A_{Max}$ , and the pressure operating range starts at  $p_{set}$  and goes to  $p_{max}$ .



When you set **Opening parameterization** to Tabulated data - Area vs. Pressure, the block calculates the opening area as

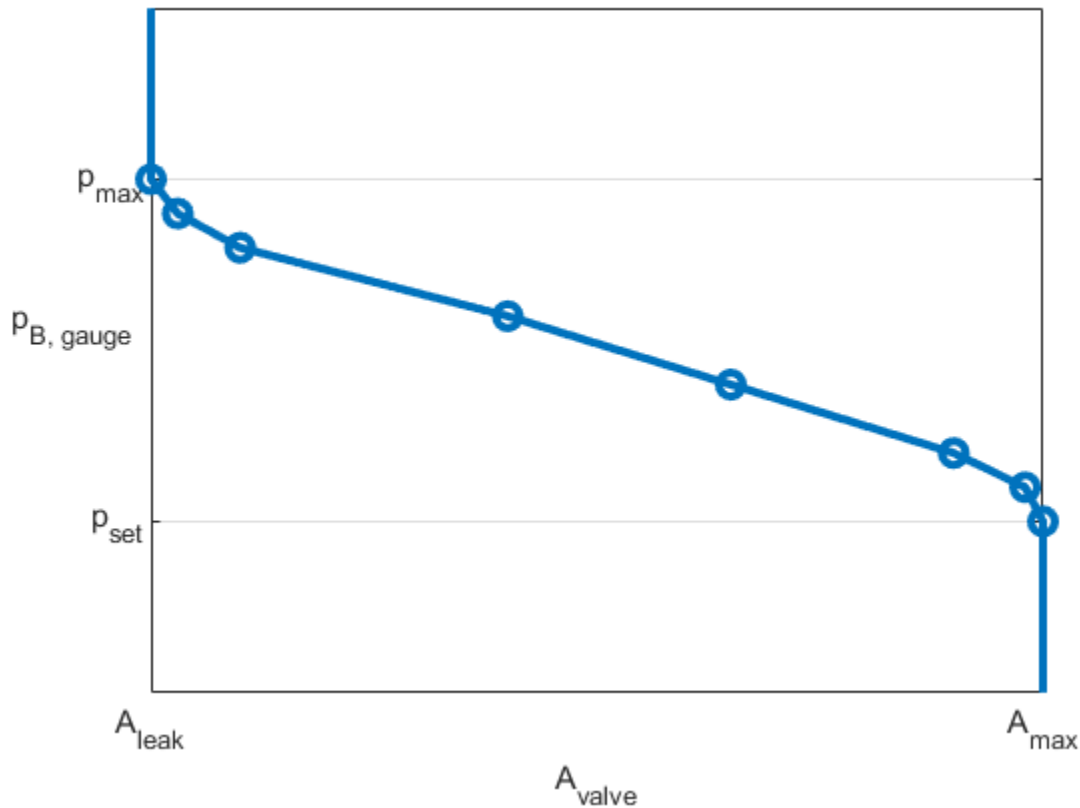
$$A_{valve} = \text{tablelookup}(p_{control, TLU}, A_{TLU}, p_{control}, \text{interpolation} = \text{linear}, \text{extrapolation} = \text{nearest}),$$

where:

- $p_{control} = p_{B,gauge}$  is the control pressure.
- $p_{control, TLU} = p_{B, TLU} + p_{offset}$ .
- $p_{B, TLU}$  is the **Port B (gauge) vector** parameter.

- $p_{offset}$  is an internal pressure offset that causes the valve to start closing when  $p_{B,Gauge} = p_{set}$ , where  $p_{offset} = p_{set} - p_{B,TLU}(1)$ .
- $A_{TLU}$  is the **Opening area vector** parameter.

$A_{max}$  and  $A_{leak}$  are the first and last parameters of the **Opening area vector** parameter, respectively. The figure demonstrates the opening characteristics of the valve when using the tabulated area parameterization.



### Conservation of Mass

When you set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. Pressure, the block conserves mass such that:

$$\dot{m}_A + \dot{m}_B = 0.$$

The block calculates the mass flow rate as

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\rho}}{\sqrt{PR_{loss} \left(1 - \left(\frac{A_{valve}}{A_{port}}\right)^2\right) [\Delta p^2 + \Delta p_{crit}^2]^{1/4}}}$$

where:

- $C_d$  is the **Discharge coefficient** parameter.

- $A_{valve}$  is the instantaneous valve open area.
- $A_{port}$  is the **Cross-sectional area at ports A and B** parameter.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number** parameter,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area. The block calculates  $PR_{loss}$  as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** parameter to Off. In this case,  $PR_{loss}$  is 1.

The block determines the opening area,  $A_{valve}$ , using the valve opening dynamics.

### Opening Dynamics

For either area parameterization, you can choose to simulate the opening dynamics of the valve response. If you select **Opening dynamics**, the block adds a lag to the flow response when the valve opens, and  $A_{valve}$  becomes the dynamic opening area,  $A_{dyn}$ . Otherwise,  $A_{valve}$  is the steady-state opening area. The block calculates the instantaneous change in the dynamic opening area based on the **Opening time constant** parameter,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, the block ignores opening dynamics.

The block calculates the steady-state dynamics based on the control pressure,  $p_{control}$ , and using the same parameterization as the valve opening.

### Volumetric Flow Rate vs. Pressure Parameterization

The volumetric flow rate parameterization equations refer to these quantities:

- $\square_{TLU,ref}$  is the **Reference volumetric flow rate vector** parameter.
- $P_{A,gauge,ref}$  and  $P_{B,gauge,ref}$  are the **Reference pressure at port A (gauge) vector** and **Reference pressure at port B (gauge) vector** parameters, respectively.
- $p_{set,gauge}$  is either the **Set pressure (gauge)** parameter or the signal at port **Ps**.
- $K$  is the flow coefficient through the reducing stage, which the block calculates during the simulation.

- $\bar{\rho}$  is the average fluid density in the reducing valve.
- $\Delta p$  is the pressure drop across the valve for fluid flow.
- $\Delta p_{crit}$  is the critical pressure drop for fluid flow.
- $C_d$  is the discharge coefficient, which the block sets internally for the volumetric flow rate parameterization.
- $Re_{crit}$  is the critical Reynolds number, which the block sets internally.
- $\nu$  is the kinematic viscosity, which is constant for the isothermal liquid network.

When you set **Opening parameterization** to **Tabulated data - Volumetric flow rate vs. pressure**, the block calculates the smoothed mass flow rate of the reducing valve such that

$$\dot{m}_{valve} = \bar{\rho} K \frac{\Delta p}{(\Delta p^2 + \Delta p_{crit}^2)^{1/4}}$$

$$\Delta p = p_A - p_B$$

$$\Delta p_{crit} = \frac{\pi \sqrt{2} \bar{\rho}}{8 C_d K} (Re_{crit} \nu)^2$$

where the block computes  $K$  using a `tablelookup` function such that

$$K = \text{tablelookup}(\Delta p_{control, TLU, Ref}, K_{TLU, Ref}, \Delta p_{control}, \text{interpolation} = \text{linear}, \text{extrapolation} = \text{nearest})$$

$$K_{TLU, Ref} = \frac{\dot{V}_{TLU, Ref}}{\sqrt{\Delta p_{TLU, Ref}}}$$

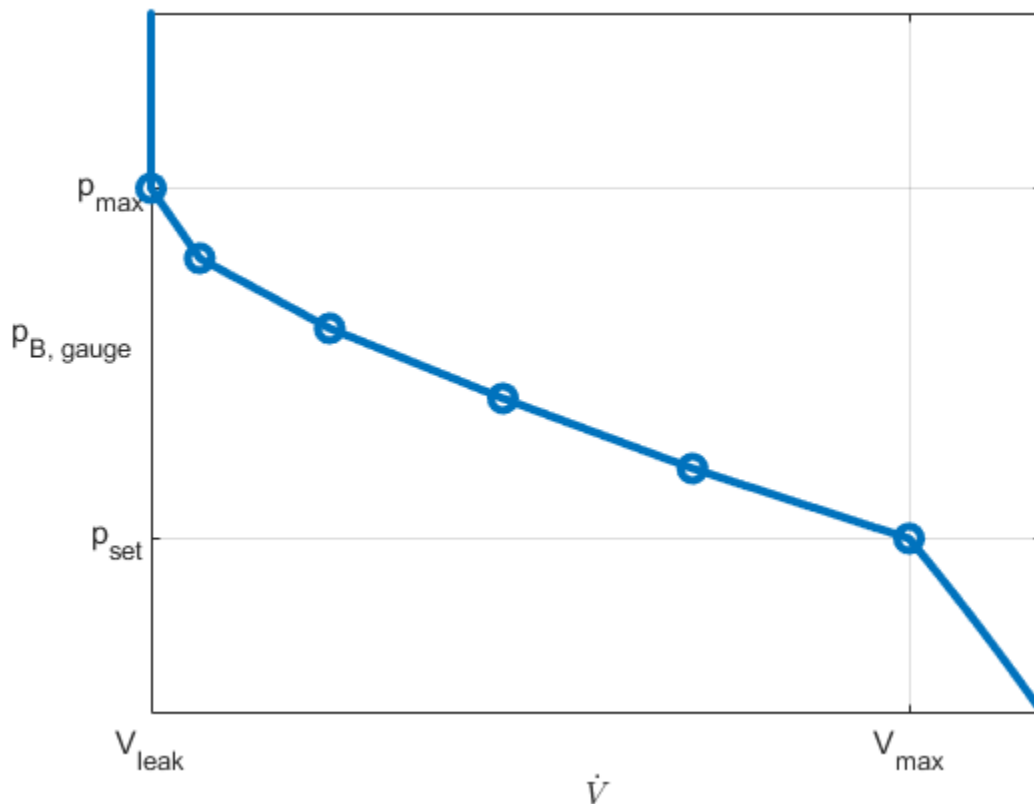
The block calculates the control pressure as

$$\Delta p_{control} = p_B - p_{drain}$$

where the block sets the drain pressure,  $p_{drain}$ , to 1 atm. The block calculates the reference control pressure vector as

$$\Delta p_{control, TLU, Ref} = p_{B, gauge, ref} + p_{offset}$$

where  $p_{offset}$  is an internally computed pressure offset that causes the valve to start shutting when  $p_{B, gauge, ref} = p_{set, gauge}$ . Thus,  $p_{offset} = p_{set, gauge} - p_{B, gauge, ref}$ . The figure shows how the block controls pressure using the tabulated volumetric flow rate parameterization.



## Faults

You can control the fault settings of the reducing valve separately from the check valve. However, the fault parameters are similar for either portion of the valve. You can set **Reducing valve fault trigger** or **Check valve fault trigger** to:

- **Temporal** — Faulting occurs at a specified time.
- **External** — Faulting occurs in response to an external trigger. This exposes port **Tr** or **Tc** for the reducing valve and the check valve, respectively.

Three fault options are available for the reducing valve and check valve. For the **Reducing valve opening when faulted** and **Check valve opening when faulted** parameters, you can choose:

- **Closed** — The valve shuts to its smallest opening value, depending on the **Opening parameterization** parameter. When you set **Opening parameterization** to:
  - **Linear - Area vs. pressure** — The valve area reduces to the value of the **Leakage area** parameter.
  - **Tabulated data - Area vs. pressure** — The valve area reduces to the value of the last element in the **Opening area vector** parameter.
  - **Tabulated data - Volumetric flow rate vs. pressure** — The flow coefficient reduces to the value of the last element of the derived flow coefficient lookup table,  $K_{TLU,Ref}$ .
- **Open** — The valve opens to its largest opening value, depending on the **Opening parameterization** parameter. When you set **Opening parameterization** to:



- **Linear - Area vs. pressure** — The valve area opens to the value of the **Maximum opening area**.
- **Tabulated data - Area vs. pressure** — The valve area opens to the value of the first element in the **Opening area vector**.
- **Tabulated data - Volumetric flow rate vs. pressure** — The flow coefficient reduces to the value of the first element of the derived flow coefficient lookup table,  $K_{TLU,Ref}$ .
- **Maintain last value** — The valve area remains at the valve opening area when the trigger occurred.

For the linear parameterization, numerical smoothing at the extremes of the valve area causes the minimum area applied to be larger than the **Leakage area** parameter, and the maximum is smaller than the **Maximum orifice area** parameter.

Once triggered, the valve remains at the faulted area for the rest of the simulation.

### Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.
- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see "List of Pre-Parameterized Components".

## Ports

### Input

#### **Ps — Set pressure signal, Pa**

physical signal

Pressure threshold for controlled valve operation, in Pa.

### Dependencies

To enable this port, set **Set pressure control** to **Controlled**.

**Tr – External reducing valve fault trigger, unitless**

physical signal

Physical signal port for a unitless external fault trigger in the reducing valve. Triggering occurs when the value is greater than 0.5.

**Dependencies**

To enable this port, set **Enable reducing valve faults** to On and **Reducing valve fault trigger** to External.

**Tc – External check valve fault trigger, unitless**

physical signal

Physical signal port for a unitless external fault trigger in the check valve. Triggering occurs when the value is greater than 0.5.

**Dependencies**

To enable this port, set **Enable check valve faults** to On and **Check valve fault trigger** to External.

**Conserving****A – Liquid port**

isothermal liquid

Entry or exit point to the valve.

**B – Liquid port**

isothermal liquid

Entry or exit point to the valve.

**Parameters****Parameters****Set pressure control – Valve operation method**

Constant (default) | Controlled

Valve operation method. When you set this parameter to **Constant**, the valve closes linearly over a fixed pressure regulation range or in accordance with the tabulated pressure and opening area data that you provide. When you set this parameter to **Controlled**, the valve closes according to a variable set pressure signal at port **Ps** over a fixed pressure regulation range.

**Opening parameterization – Opening parameterization**Linear - Area vs. pressure (default) | Tabulated data - Area vs. pressure |  
Tabulated data - Volumetric flow rate vs. pressure

Method of modeling the opening of the valve. When you select **Linear - Area vs. pressure** or **Tabulated data - Area vs. pressure**, the block relates the opening area to the control pressure. When you select **Tabulated data - Volumetric flow rate vs. pressure**, the block takes a reference flow rate and pressure differential curve of the reducing valve..

**Set pressure (gauge) – Gauge pressure beyond which valve operation triggers**

0.1 MPa (default) | positive scalar

Gauge pressure beyond which valve operation triggers. When the pressure at port **B** reaches this value, the valve begins to shut. This parameter shifts the reference curve so the reducing valve begins to close when the pressure at port **B** equals the set pressure.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant.

**Pressure regulation range – Valve operational pressure range**

1 MPa (default) | positive scalar

Operational pressure range of the valve. The pressure regulation range begins at the **Set pressure (gauge)** and the end of the range is the maximum valve operating pressure.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Maximum opening area – Area of fully opened valve**1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve in the fully open position.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Leakage area – Valve gap area when in fully closed position**1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value saturates to the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Port B (gauge) vector – Vector of gauge pressure values for tabulated area parameterization**

[0.2 : 0.2 : 1.2] MPa (default) | 1-by-n vector

Vector of gauge pressure values for the tabulated parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Opening area vector** parameter. The elements must be positive and in ascending order. The block uses linear interpolation between the data points.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Area vs. pressure.

**Opening area vector – Valve opening areas for tabulated parameterization**[1e-05, 8e-06, 6e-06, 4e-06, 2e-06, 1e-10] m<sup>2</sup> (default) | 1-by-n vector

Vector of valve opening areas for the tabulated parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Port B (gauge) vector** parameter. The elements must be positive and in ascending order. The block uses linear interpolation between the data points.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Area vs. pressure.

**Cross-sectional area at ports A and B — Area at valve entry or exit**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. The block uses these areas in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

**Pressure recovery — Option to include pressure increase during area expansions**

off (default) | on

Whether to capture the increase in pressure when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Opening dynamics — Option to include flow response to valve opening**

off (default) | on

Whether to approximate the transient effects to the fluid system due to valve opening. Selecting **Opening dynamics** approximates opening conditions by introducing a first-order lag in the flow response.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Opening time constant — Valve opening time constant**

0.1 s (default) | positive scalar

Time constant by which to compute the lag in the opening dynamics.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On and set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

**Reference pressure at port A (gauge) — Reference pressure at port A**

1.5 MPa (default) | positive scalar

Constant pressure at port **A** that forms the basis of the reference curve. This value typically corresponds to the maximum operating pressure of the valve. The pressure at port **A** can be any value during simulation.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Reference pressure at port B (gauge) vector — Reference pressure at port B**

[1.2, 1, .8, .6, .4, .2] MPa (default) | 1-by-n vector

Vector of monotonically decreasing pressure values at port **B** in the reference curve as the valve opening area changes. The first element is the reference maximum pressure, which is the pressure where the valve fully shuts. The last element is the reference set pressure.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Reference volumetric flow rate vector — Reference volumetric flow rate**

[1e-09, 1.8e-05, 6.6e-05, .00013, .0002, .00028] m<sup>3</sup>/s (default) | 1-by-n vector

Vector of monotonically increasing reference flow rates through the valve. The block uses this curve to generate a flow coefficient for the changing valve area.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Check Valve****Enable check valve – Check valve option**

off (default) | on

Whether the block simulates an internal check valve.

**Cracking pressure differential – Set pressure for check valve operation**

0.1 MPa (default) | positive scalar

Pressure differential that lifts the check valve.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Linear - Area vs. pressure.

**Maximum opening pressure differential – Maximum pressure in valve**

0.2 MPa (default) | positive scalar

Pressure differential when the check valve fully shuts.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Linear - Area vs. pressure.

**Maximum opening area – Maximum open area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum open area of the check valve in the load line. Internally, the check valve is in parallel with the reducing stage.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Linear - Area vs. pressure.

**Pressure differential vector – Pressure differential for check valve operation**

[0.01 : 0.01 : 1] MPa (default) | 1-by-*n* vector

Vector of pressure differentials for the check valve stage. The block computes the check valve pressure differential as pressure at port **B** with respect to pressure at port **A**.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Tabulated data - Area vs. pressure or Tabulated data - Volumetric flow rate vs. pressure.

**Opening area vector – Check stage opening areas**

[1e-10, 1e-05, 2e-05, 3e-05, 4e-05, 5e-05, 6e-05, 7.5e-05, 8.5e-05, .0001] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of opening areas for the check valve stage. The vector elements must correspond one-to-one with the elements in the **Pressure differential vector** parameter.

#### Dependencies

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Tabulated data - Area vs. pressure.

#### Volumetric flow rate vector — Check stage volumetric flow rates

[.000358, .045, .11, .191, .284, .39, .505, .63, .764, .905] .\* 1e-3 m<sup>3</sup>/s  
(default) | 1-by-*n* vector

Vector of volumetric flow rates for the check valve stage. The elements of this vector must correspond to the elements in the **Pressure differential vector** parameter.

#### Dependencies

To enable this parameter, set **Enable check valve** to On and **Valve parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

#### Faults

#### Enable reducing valve fault — Reducing valve fault option

off (default) | on

Whether to enable the fault parameters for the reducing valve. When faulting occurs, the block sets the opening area to the position specified by the **Reducing valve opening when faulted** parameter.

#### Reducing valve opening when faulted — Reducing valve fault position

Closed (default) | Open | Maintain last value

Reducing valve position when the fault triggers. You can choose for the valve to fault open, shut, or in place.

#### Dependencies

To enable this parameter, set **Enable reducing valve fault** to On.

#### Reducing valve fault trigger — External or temporal reducing valve trigger option

Temporal (default) | External

Whether a reducing valve fault trigger occurs due to an external event or at a specified time. When you set this parameter to:

- **External**, the block enables port **Tr**. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.
- **Temporal**, when the **Simulation time for reducing valve fault event** is reached, the block sets the valve area to the value specified in the **Reducing valve opening when faulted** parameter.

#### Dependencies

To enable this parameter, set **Enable reducing valve fault** to On.

#### Simulation time for reducing valve fault event — Time at which reducing valve fault triggers

5 s (default) | positive scalar

Simulation time at which the block sets the opening area to the position specified by the **Reducing valve opening when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable reducing valve fault** to On and **Reducing valve fault trigger** to Temporal.

**Enable check valve fault — Check valve fault option**

off (default) | on

Whether to enable the fault parameters for the check valve. When faulting occurs, the block sets the opening area to the position specified by the **Check valve opening when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable check valve** to On.

**Check valve opening when faulted — Check valve fault position**

Closed (default) | Open | Maintain last value

Check valve position when the fault triggers. You can choose for the valve to fault open, shut, or in place.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Enable check valve fault** to On.

**Check valve fault trigger — External or temporal check valve trigger option**

Temporal (default) | External

Whether a check valve fault trigger occurs due to an external event or at a specified time. When you set this parameter to:

- **External**, the block enables port **Tc**. A physical signal at port **Tc** that is greater than 0.5 triggers faulting.
- **Temporal**, when the **Simulation time for check valve fault event** is reached, the valve area will be set to the value specified in the **Check valve opening when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable check valve** to On and **Enable check valve fault** to On.

**Simulation time for check valve fault event — Time at which check valve fault triggers**

5 s (default) | positive scalar

Simulation time at which the block sets the opening area to the position specified by the **Check valve opening when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable check valve** to On, **Enable check valve fault** to On, and **Check valve fault trigger** to Temporal.



## Version History

Introduced in R2020a

### Parameterize by volumetric flow rate vs. pressure

You can set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

### Access pre-parameterized block options

The block supports pre-parameterization options. Suppliers include Hawe Hydraulik, Rexroth Bosch Group, and Sun Hydraulics.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Pressure Compensator Valve (IL) | Pressure-Reducing 3-Way Valve (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure-Compensated Flow Control Valve (IL)

# Pressure Reducing Valve (G)

Pressure reducing valve in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Pressure Control Valves



## Description

The Pressure Reducing Valve (G) block represents a valve that constricts to maintain a preset gauge pressure at its outlet, port **B**. The normally open valve begins to close when the outlet pressure, measured against atmospheric pressure, rises above the valve pressure setting. The opening area falls with the pressure drop down to a minimum, where the valve is fully closed and only leakage flow remains.

The relationship between the opening area and the pressure drop depends on the parameterization of the valve. That relationship can take the form of a linear analytical expression or a tabulated function.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

## Control and Other Pressures

The pressure at the outlet is the control signal of the valve. The more the outlet pressure rises over the pressure setting of the valve, the smaller the opening area becomes. The control pressure,  $P_{Ctl}$ , is

$$P_{Ctl} = P_B - P_{Atm}$$

where  $P_B$  is the instantaneous pressure at port **B** and  $P_{Atm}$  is the atmospheric pressure specified in the Gas Properties (G) block of the model. Both pressures are determined during simulation as absolute pressures.

The pressure setting,  $P_{Set}$ , of the valve is the value of the **Set pressure (gauge)** parameter when the **Opening characteristic** parameter is **Linear**. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Set}$  is the first element of the **Port B pressure (gauge) vector** parameter.

The maximum pressure,  $P_{Max}$ , is  $P_{Max} = P_{Set} + \Delta P$ , where  $\Delta P$  is the pressure regulation range of the valve when the **Opening characteristic** parameter is **Linear**. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Set}$  is the last element of the **Port B pressure (gauge) vector** parameter.

## Fraction of Valve Opening

The degree to which the control pressure exceeds the pressure setting determines how much the valve opens. When the **Opening characteristic** parameter is **Linear**, the block calculates the valve opening fraction to scale the flow characteristic parameters. The valve opening fraction is

$$\hat{P} = 1 - \frac{P_{Ctl} - P_{Set}}{\Delta P},$$

where:

- $P_{Ctl}$  is the control pressure.
- $P_{Set}$  is the pressure setting specified by the **Set pressure (gauge)** parameter.
- $\Delta P$  is the pressure regulation range specified by the **Pressure regulation range** parameter.

The fraction is normalized so that it is 0 in the fully closed valve and 1 in the fully open valve. If the calculation returns a value outside of these bounds, the block saturates the value to the nearest of the two limits.

### Numerical Smoothing

When the **Opening characteristic** parameter is **Linear** and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized control pressure,  $\hat{P}$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

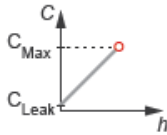
- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parameterization.

### Opening Characteristics

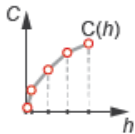
The flow characteristic relates the opening of the valve to the input that produces it. The opening is expressed as a sonic conductance, flow coefficient, or restriction area, determined by the **Valve parameterization** parameter.

The flow characteristic is normally given at steady state, with the inlet at a constant, carefully controlled pressure. This inherent flow characteristic depends only on the valve and it can be linear or nonlinear, the most common examples of the latter being the quick-opening and equal-percentage types. To capture such flow characteristics, the block provides a choice for the **Opening characteristic** parameter:

- **Linear** — The measure of flow capacity is a linear function of the orifice opening fraction. As the opening fraction rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.



- **Tabulated** — The measure of flow capacity is a general function, which can be linear or nonlinear, of the orifice opening fraction. The function is specified in tabulated form, with the independent variable specified by the **Port B pressure (gauge) vector**.



### Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3 p_{in} F_\gamma x_T},$$

where:

- $F_\gamma$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3 F_\gamma x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma}x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3}C_v N_6 \sqrt{F_{\gamma} x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{\frac{p_{out}}{p_{in}} - B_{crit}}{1 - B_{crit}}} \right)^2 \right]^m,$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C \rho_{ref} \sqrt{\frac{T_{ref}}{T_{avg}}} \left[ 1 - \left( \frac{B_{lam} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m \left( \frac{p_{in} - p_{out}}{1 - B_{lam}} \right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left( \frac{p_{out}}{p_{in}} \right)^{\frac{\gamma-1}{\gamma}}}{1 - \left( \frac{S_R}{S} \right)^2 \left( \frac{p_{out}}{p_{in}} \right)^{\frac{2}{\gamma}}} \right]}.$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \left[ \frac{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}} \right] \left( \frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma-1}{\gamma}}} \right)}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

## Assumptions and Limitations

- The `Sonic conductance` setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the `Orifice area` parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Conserving

#### A — Valve entrance

gas

Gas conserving port associated with the opening through which the flow must enter the valve.

#### B — Valve entrance

gas

Gas conserving port associated with the opening through which the flow must exit the valve.

## Parameters

**Valve parameterization — Parameterization used to specify flow characteristics of orifice**  
`Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area`

Method to calculate the mass flow rate.

- `Cv flow coefficient` — The flow coefficient  $C_v$  determines the block parameterization.
- `Kv flow coefficient` — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- `Sonic conductance` — The sonic conductance of the resistive element at steady state determines the block parameterization.
- `Orifice area` — The size of the flow restriction determines the block parameterization.

**Opening characteristic — Method to calculate the opening characteristics of the valve**  
`Linear (default) | Tabulated`

Method the block uses to calculate the opening area of the valve. The linear setting treats the opening area as a linear function of the orifice opening fraction. The tabulated setting allows for a general, nonlinear relationship you can specify in tabulated form.

**Set pressure (gauge) — Outlet gauge pressure required to close valve**  
`0.1 MPa (default) | scalar`

Outlet gauge pressure required to close the valve. This parameter marks the beginning of the pressure regulation range, over which the valve progressively closes in an effort to contain a pressure rise. The opening area of the valve depends on the difference between the actual outlet pressure to the value specified here.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Pressure regulation range — Width of the pressure range over which the opening area is variable**

0.1 MPa (default) | scalar

Width of the pressure range over which the opening area of the valve is variable. The pressure range begins at the value of the **Set pressure (gauge)** parameter. It ends at the sum of the values of this parameter and the **Set pressure (gauge)** parameter. The smaller the pressure regulation range, the greater the impact of a unit pressure rise on the opening area of the valve.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Linear.

**Port B pressure (gauge) vector — Vector of control pressures at which to specify valve opening data**

0.2 : 0.2 : 1.2 MPa (default) | vector in units of pressure

Vector of control pressures at which to specify the chosen measure of valve opening—sonic conductance, flow coefficient, or opening area. This vector must be equal in size to those containing the valve opening data. The vector elements must be positive and increase monotonically in value from left to right.

The first vector element gives the pressure setting of the valve where the valve begins to close. This element is equivalent to the **Set pressure (gauge)** parameter of the Linear opening parameterizations. The last element gives the maximum pressure, at which the valve is maximally closed and only leakage flow remains. The difference between the two gives the pressure regulation range of the valve.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated.

**Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Linear.

**xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.



**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Leakage flow fraction — Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Cv flow coefficient vector — Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector — Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers

Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Kv flow coefficient`, and **Opening characteristic** to `Tabulated`.

**Maximum sonic conductance — Sonic conductance corresponding to maximally open component**

12  $\text{l}/(\text{bar}\cdot\text{s})$  (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Linear`.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Linear`.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**ISO reference density — ISO 8778 reference density**

1.185  $\text{kg}/\text{m}^3$  (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185  $\text{kg}/\text{m}^3$  in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12]  $l/(bar*s)$  (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**, and **Opening characteristic** to **Tabulated**.

**Critical pressure ratio vector — Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Sonic conductance**, and **Opening characteristic** to **Tabulated**.

**Maximum orifice area — Flow area corresponding to maximally open component**

1e-4  $m^2$  (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Orifice area**, and **Opening characteristic** to **Linear**.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Orifice area**.

**Orifice area vector — Vector of orifice opening area values**

[1e-10, 2e-05, 4e-05, 6e-05, 8e-05, .0001]  $m^2$  (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

#### **Dependencies**

To enable this parameter, set **Valve parameterization** to Orifice area, and **Opening characteristic** to Tabulated.

#### **Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

#### **Cross-sectional area at ports A and B – Flow area at gas ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## **Version History**

### **Introduced in R2018b**

#### **Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.
- The **Control pressure vector** parameter has been renamed to **Port B pressure (gauge) vector**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Orifice (G) | Pressure Relief Valve (G)

## Pressure Reducing Valve (TL)

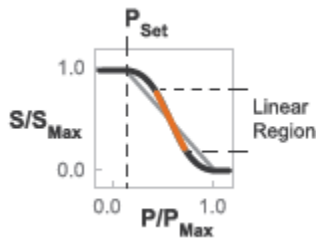
Pressure reducing valve in a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Pressure Control Valves



### Description

The Pressure Reducing Valve (TL) block represents a valve that reduces downstream pressure in a thermal liquid network. The valve is fully open when the pressure at port **B** is lower than the value of the **Valve set pressure (gauge)** parameter. At the set pressure, the valve control member moves to reduce the flow rate through the valve. The valve opening area gets smaller as pressure rises until the flow only consists of leakage. The figure illustrates the valve operation and smoothing.



### Mass Balance

The mass conservation equation in the valve is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate into the valve through port **A**.
- $\dot{m}_B$  is the mass flow rate into the valve through port **B**.

### Momentum Balance

The momentum conservation equation in the valve is

$$p_A - p_B = \frac{\dot{m}\sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{2\rho_{Avg}C_d^2S^2} \left[ 1 - \left( \frac{S_R}{S} \right)^2 \right] PR_{Loss},$$

where:

- $p_A$  and  $p_B$  are the pressures at port **A** and port **B**.
- $\dot{m}$  is the mass flow rate.

- $\dot{m}_{cr}$  is the critical mass flow rate.
- $\rho_{Avg}$  is the average liquid density.
- $C_d$  is the discharge coefficient.
- $S_R$  is the valve opening area.
- $S$  is the valve inlet area.
- $PR_{Loss}$  is the pressure ratio:

$$PR_{Loss} = \frac{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} - C_d(S_R/S)}{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} + C_d(S_R/S)}$$

The block computes the valve opening area as

$$S_R = \hat{p}_{smoothed} \cdot (S_{Leak} - S_{Max}) + S_{Max}$$

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{Max} - p_{set}}$$

where:

- $S_{Leak}$  is the valve leakage area.
- $S_{Linear}$  is the linear valve opening area:
- $S_{Max}$  is the maximum valve opening area.
- $p_{control}$  is the valve control pressure:

$$p_{control} = p_B$$

- $p_{set}$  is the valve set pressure:

$$p_{set} = p_{set, gauge} + p_{Atm}$$

- $p_{Min}$  is the minimum pressure.
- $p_{Max}$  is the maximum pressure:

$$p_{max} = p_{set, gauge} + p_{range} + p_{Atm}$$

- $\Delta p$  is the portion of the pressure range to smooth.

The critical mass flow rate is

$$\dot{m}_{cr} = Re_{cr} \mu_{Avg} \sqrt{\frac{\pi}{4}} S_R$$

### Numerically-Smoothed Valve Area

When the valve is in a near-open or near-closed position, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{Max}$ . For more information, see "Numerical Smoothing".

### Energy Balance

The energy conservation equation in the valve is

$$\phi_A + \phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate into the valve through port **A**.
- $\phi_B$  is the energy flow rate into the valve through port **B**.

## Ports

### Conserving

#### **A – Liquid port**

thermal liquid

Thermal liquid conserving port associated with valve inlet A.

#### **B – Liquid port**

thermal liquid

Thermal liquid conserving port associated with valve inlet B.

## Parameters

### **Valve set pressure (gauge) – Gauge pressure beyond which valve operation triggers**

0.1 MPa (default) | positive scalar

Pressure at which the valve begins to shut. The opening area remains variable throughout the pressure regulation range of the valve.

### **Pressure regulation range – Valve pressure range**

0.01 MPa (default) | positive scalar

Pressure interval over which the valve opening area varies. The interval begins at the value of the **Valve set pressure (gauge)** parameter.

### **Maximum opening area – Opening area in the fully open position due to sealing imperfections**

1e-4 m<sup>2</sup> (default) | positive scalar

Opening area of the valve in the fully open position, when the valve is at the lower limit of the pressure regulation range. The block uses this parameter to scale the valve opening throughout the pressure regulation range.

### **Leakage area – Gap area when in fully closed position**

1e-12 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully shut position. The block saturates smaller numbers to this value. This parameter contributes to numerical stability by maintaining continuity in the flow.

### **Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]



Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Cross-sectional area at ports A and B – Area at conserving ports**

0.01 m<sup>2</sup> (default) | positive scalar

Area at ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient – Discharge coefficient**

0.7 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure Relief Valve (TL)

## Pressure-Reducing Valve (2P)

Pressure-reducing valve in a two-phase fluid network

**Library:** Simscape / Fluids / Two-Phase Fluid / Valves & Orifices / Pressure Control Valves



### Description

The Pressure-Reducing Valve (2P) block models a pressure-controlling reducing valve in a two-phase fluid network. The valve is open when the pressure at port **B** is less than the set pressure, and closes when the pressure exceeds that value. The control pressure can be set as a constant in the **Set pressure (gauge)** parameter or, when you set **Set pressure control** to **Controlled**, the set pressure can vary according to the input signal at port **Ps**.

Fluid properties inside the valve are calculated from inlet conditions. There is no heat exchange between the fluid and the environment, and therefore phase change inside the valve only occurs due to a pressure drop or a propagated phase change from another part of the model.

A number of block parameters are based on nominal operating conditions, which correspond to the valve rated performance, such as a specification on a manufacturer datasheet.

### Pressure Control

The valve closes when the pressure in the valve,  $p_{control}$ , exceeds the set pressure,  $p_{set}$ . The valve is fully closed when the control pressure reaches the end of the **Pressure regulation range**,  $p_{range}$ .

When you set **Set pressure control** to **Constant**, the opening fraction of the valve,  $\lambda$ , is expressed as:

$$\lambda = 1 - (1 - f_{leak}) \frac{(p_{control} - p_{set})}{p_{range}},$$

where:

- $f_{leak}$  is the **Closed valve leakage as a fraction of nominal flow**.
- $p_{control}$  is the control pressure, which is the difference between the pressure at port **B** and atmospheric pressure.
- $p_{set}$  is the **Set pressure (gauge)**.

When you set **Set pressure control** to **Controlled**, the valve opening fraction is:

$$\lambda = 1 - (1 - f_{leak}) \frac{(p_{control} - p_s)}{p_{range}},$$

where  $p_s$  is the signal at port **Ps**. If the control pressure exceeds the valve pressure range, the valve opening fraction is 0.

### Mass Flow Rate

The mass flow rate depends on the pressure differential, and therefore the open area of the valve. It is calculated as:

$$\dot{m}_A = \lambda \dot{m}_{nom} \left[ \sqrt{\frac{v_{nom}}{2\Delta p_{nom}}} \right] \sqrt{\frac{2}{v_{in} (\Delta p^2 + \Delta p_{lam}^2)^{0.25}}},$$

where:

- $\Delta p$  is the pressure drop over the valve,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure transition threshold between laminar and turbulent flow, which is calculated from the **Laminar flow pressure ratio**,  $B_{lam}$ :

$$\Delta p_{lam} = \frac{(p_A + p_B)}{2} (1 - B_{lam}).$$

- $\dot{m}_{nom}$  is the **Nominal mass flow rate at maximum opening**.
- $\Delta p_{nom}$  is the **Nominal pressure drop rate at maximum opening**.
- $v_{nom}$  is the nominal inlet specific volume. This value is determined from the fluid properties tabulated data based on the **Nominal inlet specific enthalpy** and **Nominal inlet pressure** parameters.
- $v_{in}$  is the inlet specific volume.

### Fluid Specific Volume Dynamics

When the fluid at the valve inlet is a liquid-vapor mixture, the block calculates the specific volume as:

$$v_{in} = (1 - x_{dyn})v_{liq} + x_{dyn}v_{vap},$$

where:

- $x_{dyn}$  is the inlet vapor quality. The block applies a first-order lag to the inlet vapor quality of the mixture.
- $v_{liq}$  is the liquid specific volume of the fluid.
- $v_{vap}$  is the vapor specific volume of the fluid.

If the inlet fluid is liquid or vapor,  $v_{in}$  is the respective liquid or vapor specific volume.

### Vapor quality lag

If the inlet vapor quality is a liquid-vapor mixture, a first-order time lag is applied:

$$\frac{dx_{dyn}}{dt} = \frac{x_{in} - x_{dyn}}{\tau},$$

where:

- $x_{dyn}$  is the dynamic fluid vapor quality.
- $x_{in}$  is the current inlet vapor quality.
- $\tau$  is the **Inlet phase change time constant**.

If the inlet fluid is a subcooled liquid or superheated vapor,  $x_{dyn}$  is equal to  $x_{in}$ .

**Mass Balance**

Mass is conserved in the valve:

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

**Energy Balance**

Energy is conserved in the valve:

$$\Phi_A + \Phi_B = 0,$$

where:

- $\Phi_A$  is the energy flow at port **A**.
- $\Phi_B$  is the energy flow at port **B**.

**Assumptions and Limitations**

- The block does not model pressure recovery downstream of the valve.
- There is no heat exchange between the valve and the environment.
- The block does not model choked flow.

**Ports****Conserving****A — Fluid port**

two-phase fluid

Fluid entry or exit port.

**B — Fluid port**

two-phase fluid

Fluid entry or exit port.

**Input****Ps — Set pressure**

physical signal

Input port for varying the set pressure signal.

**Dependencies**

To enable this port, set **Set pressure control** to **Controlled**.

## Parameters

### Set pressure control — Varying or constant set pressure

Constant (default) | Controlled

Whether the pressure threshold is constant or variable. Setting this parameter to `Controlled` exposes the physical signal port **Ps**.

### Set pressure (gauge) — Pressure threshold

0.1 MPa (default) | positive scalar

Valve pressure threshold. When the control pressure,  $p_B - p_{atm}$ , exceeds the set pressure, the valve begins to close.

### Dependencies

To enable this parameter, set **Set pressure control** to `Constant`.

### Pressure regulation range — Valve operational range

0.1 MPa (default) | positive scalar

Valve operational range. The valve begins to close at the set pressure value, and is fully closed at  $p_{max}$ , the end of the pressure regulation range:  $p_{max} = p_{set} + p_{range}$ .

### Nominal mass flow rate at maximum opening — Rated mass flow rate

0.1 kg/s (default) | positive scalar

Mass flow rate through a fully open valve under typical, design, or rated conditions.

### Nominal pressure drop at maximum opening — Rated pressure drop

0.001 MPa (default) | positive scalar

Pressure drop over a fully open valve under typical, design, or rated conditions.

### Nominal inlet condition specification — Method of determining inlet fluid state

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Method of determining inlet fluid state. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

### Nominal inlet pressure — Pressure of fluid entering valve

0.101325 MPa (default) | positive scalar

Inlet pressure in typical, design, or rated conditions. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

### Nominal inlet temperature — Fluid temperature

293.15 K (default) | positive scalar

Inlet fluid temperature in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Inlet vapor quality by mass fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet vapor quality of the mixture by mass fraction in open, nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor quality.

**Nominal inlet vapor void fraction — Inlet vapor quality by volume fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet mixture volume fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor void fraction.

**Nominal inlet specific enthalpy — Inlet fluid specific enthalpy**

1500 kJ/kg (default) | positive scalar

Inlet specific enthalpy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific enthalpy.

**Nominal inlet specific internal energy — Inlet specific internal energy**

1500 kJ/kg (default) | positive scalar

Inlet specific internal energy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific internal energy.

**Cross-sectional area at ports A and B — Valve port areas**

0.01 m<sup>2</sup> (default) | positive scalar

Area of the valve ports **A** and **B**.

**Closed valve leakage as a fraction of nominal flow — Fractional flow when valve is closed**

1e-6 (default) | positive scalar

Fractional flow rate through the valve when it is fully closed. This parameter contributes to numerical stability by maintaining continuity in the fluid network.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio – Laminar-turbulent transition pressure ratio**

0.999 (default) | positive scalar

Ratio of the valve outlet pressure to valve inlet pressure at which the fluid transitions between the laminar and turbulent regimes. The pressure loss corresponds to the mass flow rate linearly in laminar flows and quadratically in turbulent flows.

**Inlet phase change time constant – Lag for mixture specific volume**

0.1 s (default) | positive scalar

Time lag for liquid-vapor mixtures in computing the fluid specific volume. This parameter does not influence the specific volume when the inlet fluid is a fully supercooled liquid or fully superheated vapor.

## Version History

Introduced in R2021a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure-Reducing Valve (2P) | Check Valve (2P) | Orifice (2P) | Thermostatic Expansion Valve (2P)

# Pressure Relief Valve

Valve used to vent pressure in excess of a preset value from a hydraulic line

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Valves / Pressure Control Valves



## Description

The Pressure Relief Valve block models the flow through a valve that opens to vent so as to maintain a preset pressure drop between inlet (port **A**) and outlet (port **B**). The normally closed valve cracks open when the pressure drop from **A** to **B** exceeds the valve pressure setting. The valve opening area is computed as a function of the excess in the pressure drop, either a simple linear expression or a (generally nonlinear) tabulated function. The valve serves its purpose until its opening area reaches a maximum—a point at the limit of the valve regulation range, beyond which the pressure drop is again free to rise, unabated.

## Valve Opening

The opening area calculation depends on the valve parameterization selected for the block: either Linear area-opening relationship or Tabulated data - Area vs. pressure.

### Linear Parameterization

If the **Valve parameterization** block parameter is in the default setting of Linear area-opening relationship, the opening area is computed as:

$$S(\Delta p_{AB}) = S_{Leak} + k(\Delta p_{AB} - \Delta p_{Set}),$$

where:

- $S_{Max}$  is the value specified in the **Maximum passage area** block parameter.
- $\Delta p_{Set}$  is the value specified in the **Valve pressure setting** block parameter.
- $\Delta p_{AB}$  is the pressure drop from port **A** to port **B**:

$$\Delta p_{AB} = p_A - p_B,$$

where  $p$  is the gauge pressure at the port indicated by the subscript (**A** or **B**).

- $k$  is the linear constant of proportionality:

$$k = \frac{S_{Max} - S_{Leak}}{\Delta p_{Reg}},$$

where in turn:

- $S_{Leak}$  is the value specified in the **Leakage area** block parameter.
- $\Delta p_{Reg}$  is that specified in the **Valve regulation range** block parameter.



At and below the valve pressure setting, the opening area is that due to internal leakage alone:

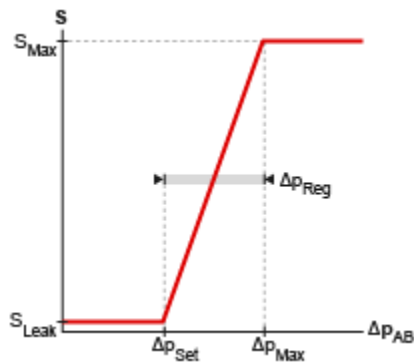
$$S(\Delta p_{AB} \leq \Delta p_{Set}) = S_{Leak}$$

At and above a maximum pressure, the opening area is that of a fully open valve:

$$S(\Delta p_{AB} \geq \Delta p_{Max}) = S_{Max}$$

where the maximum pressure drop  $\Delta p_{Max}$  is the sum:

$$\Delta p_{Max} = \Delta p_{Set} + \Delta p_{Reg}$$



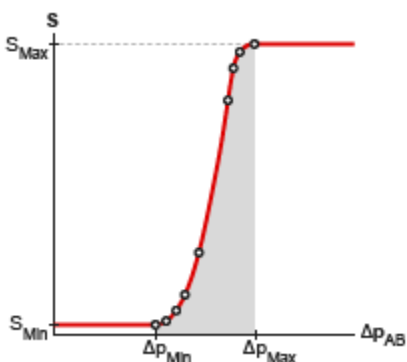
### Opening area in the Linear area-opening relationship parameterization

#### Tabulated Parameterization

If the **Valve parameterization** block parameter is set to Tabulated data - Area vs. pressure, the opening area is computed as:

$$S = S(\Delta p_{AB}),$$

where  $S_{XY}$  is a tabulated function constructed from the **Pressure drop vector** and **Opening area vector** block parameters. The function is based on linear interpolation (for points within the data range) and nearest-neighbor extrapolation (for points outside the data range). The leakage and maximum opening areas are the minimum and maximum values of the **Valve opening area vector** block parameter.



### Opening area in the Tabulated data - Area vs. pressure parameterization

### Opening Dynamics

By default, the valve opening dynamics are ignored. The valve is assumed to respond instantaneously to changes in the pressure drop, without time lag between the onset of a pressure disturbance and the increased valve opening that the disturbance produces. If such time lags are of consequence in a model, you can capture them by setting the **Opening dynamics** block parameter to `Include valve opening dynamics`. The valves then open each at a rate given by the expression:

$$\dot{S} = \frac{S(\Delta p_{SS}) - S(\Delta p_{In})}{\tau},$$

where  $\tau$  is a measure of the time needed for the instantaneous opening area (subscript In) to reach a new steady-state value (subscript SS).

### Leakage Area

The primary purpose of the leakage area of a closed valve is to ensure that at no time does a portion of the hydraulic network become isolated from the remainder of the model. Such isolated portions reduce the numerical robustness of the model and can slow down simulation or cause it to fail. Leakage is generally present in minuscule amounts in real valves but in a model its exact value is less important than its being a small number greater than zero. The leakage area is obtained from the block parameter of the same name.

### Valve Flow Rate

The causes of the pressure losses incurred in the passages of the valve are ignored in the block. Whatever their natures—sudden area changes, flow passage contortions—only their cumulative effect is considered during simulation. This effect is captured in the block by the discharge coefficient, a measure of the flow rate through the valve relative to the theoretical value that it would have in an ideal valve. The flow rate through the valve is defined as:

$$q = C_D S \sqrt{\frac{2}{\rho} \frac{\Delta p_{AB}}{[(\Delta p_{AB})^2 + p_{Crit}^2]^{1/4}}},$$

where:

- $q$  is the volumetric flow rate through the valve.
- $C_D$  is the value of the **Discharge coefficient** block parameter.
- $S$  is the opening area of the valve.
- $\Delta p_{AB}$  is the pressure drop from port **A** to port **B**.
- $p_{Crit}$  is the pressure differential at which the flow shifts between the laminar and turbulent flow regimes.

The calculation of the critical pressure depends on the setting of the **Laminar transition specification** block parameter. If this parameter is in the default setting of `By pressure ratio`:

$$p_{Crit} = (p_{Atm} + p_{Avg})(1 - \beta_{Crit}),$$

where:

- $p_{Atm}$  is the atmospheric pressure (as defined for the corresponding hydraulic network).
- $p_{Avg}$  is the average of the gauge pressures at ports **A** and **B**.

- $\beta_{\text{Crit}}$  is the value of the **Laminar flow pressure ratio** block parameter.

If the **Laminar transition specification** block parameter is instead set to By Reynolds number:

$$p_{\text{Crit}} = \frac{\rho}{2} \left( \frac{Re_{\text{Crit}} \nu}{C_D D_H} \right)^2,$$

where:

- $Re_{\text{Crit}}$  is the value of the **Critical Reynolds number** block parameter.
- $\nu$  is the kinematic viscosity specified for the hydraulic network.
- $D_H$  is the instantaneous hydraulic diameter:

$$D_H = \sqrt{\frac{4S}{\pi}}.$$

## Ports

### Conserving

#### A – Valve inlet

hydraulic (isothermal liquid)

Opening through which the flow can enter the valve.

#### B – Valve outlet

hydraulic (isothermal liquid)

Opening through which the flow can exit the valve.

## Parameters

### Opening area parameterization – Method of calculating the opening area of the valve

Linear area-opening relationship (default) | Tabulated data - Area vs. pressure

Method by which to calculate the opening area of the valve. The default setting prescribes a linear relationship between the opening area of the valve and the pressure drop between its sensor ports. The alternative setting allows for a general, nonlinear relationship to be specified in tabulated form.

### Maximum passage area – Opening area of the valve in the fully open position

1e-4 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully open position. The valve is fully open if the pressure drop from port **A** to port **B** is in excess of that given by the sum of the **Valve pressure setting** and **Valve regulation range** block parameters.

### Dependencies

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

### Valve pressure setting – Pressure drop to maintain from port A to port B

30e5 Pa (default) | positive scalar in units of pressure

Pressure drop from port **A** to port **B** that the valve is to maintain. The valve begins to open when the pressure drop exceeds the value specified here. If the pressure drop is less than this value, the valve is maximally closed and the opening area is that given in the **Leakage area** block parameter.

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

**Valve regulation range – Pressure drop interval over which the valve is to designed to operate**

1.5e5 Pa (default) | positive scalar in units of pressure

Pressure drop interval over which the valve is designed to operate. This interval stretches from the largest pressure drop at which the valve is maximally closed to the lowest pressure drop at which the valve is fully open. Only within this range is the valve capable of maintaining the specified pressure setting.

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

**Flow Discharge coefficient – Empirical factor defined as the ratio of actual to ideal mass flow rates**

0.7 (default) | positive unitless scalar

Ratio of the actual flow rate through the valve to the theoretical value that it would have in an ideal valve. This semi-empirical parameter measures the flow allowed through the valve: the greater its value, the greater the flow rate. Refer to the valve data sheet, if available, for this parameter.

**Leakage area – Opening area of the valve in the maximally closed position**

1e-10 m<sup>2</sup> (default) | positive scalar in units of area

Opening area of the valve in the fully closed position, when only internal leakage between its ports remains. This parameter serves primarily to ensure that closure of the valve does not cause portions of the thermal liquid network to become isolated. The exact value specified here is less important than its being a small number greater than zero.

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Linear area-pressure relationship.

**Pressure differential vector – Vector of pressure drops at which to tabulate the valve opening areas**

[30.15E5 : 15E3 : 31.35E5] Pa (default) | vector of positive numbers in units of pressure

Vector of pressure drops from port **A** to port **B** at which to specify the opening area of the valve. The vector elements must increase monotonically from left to right. This order is important when specifying the **Opening area vector** block parameter.

The block uses this data to construct a lookup table by which to determine from the gauge pressure at port **B** the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Opening area vector — Vector of opening areas at the specified pressure differential breakpoints**

[9E-5 : -1 : 1E-5] m<sup>2</sup> (default) | vector of positive numbers in units of area

Vector of opening areas corresponding to the breakpoints defined in the **Pressure differential vector** block parameter. The vector elements must increase monotonically from left to right (the direction of increasing pressure). For best results, avoid regions of flattened slope.

The block uses this data to construct a lookup table by which to determine from the pressure differential the valve opening area. Data is handled with linear interpolation (within the tabulated data range) and nearest-neighbor extrapolation (outside of the range).

**Dependencies**

This parameter is active when the **Opening area parameterization** block parameter is set to Tabulated data - Area vs. pressure.

**Laminar transition specification — Parameter in terms of which to define the boundary between laminar and turbulent regimes**

Pressure ratio (default) | Reynolds number

Parameter in terms of which to specify the boundary between the laminar and turbulent flow regimes. The pressure ratio of the default parameterization is defined as the gauge pressure at the outlet divided by the same at the inlet.

**Laminar flow pressure ratio — Pressure ratio at which the flow transitions between laminar and turbulent regimes**

0.999 (default) | positive unitless scalar

Pressure ratio at which the flow is assumed to transition between laminar and turbulent regimes. The pressure ratio is defined as the gauge pressure at the outlet divided by the same at the inlet. The transition is assumed to be smooth and centered on this value.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Reynolds number.

**Critical Reynolds number — Reynolds number at the boundary between laminar and turbulent flow regimes**

12 (default) | positive unitless scalar

Reynolds number at which the flow is assumed to transition between laminar and turbulent regimes.

**Dependencies**

This parameter is active when the **Laminar transition specification** block parameter is set to Pressure ratio.

**Opening dynamics — Choice of whether to capture the opening dynamics of the valve**

Do not include valve opening dynamics (default) | Include valve opening dynamics

Choice of whether to capture the opening dynamics of the valve. Selecting `Include valve opening dynamics` causes the valve to open gradually, so as to approach its new steady-state area over a small time span. The characteristic time for such transitions is given in the **Opening time constant** block parameter.

Setting this parameter to the alternative `Do not include valve opening dynamics` is equivalent to specifying a value of  $\infty$  for the opening time constant. The opening area is in this case assumed to reach its new steady-state value instantaneously.

Include opening dynamics to more accurately capture the behavior of a real valve. For best real-time simulation performance, use with a local solver or disable valve opening dynamics altogether.

### **Opening time constant — Characteristic time scale of the valve opening transitions**

$0.1 \text{ s}$  (default) | positive scalar in units of time

Measure of the time taken by the valve to transition from its current opening area to a new steady-state value. The block uses this parameter to calculate the rate at which a valve is opening and from it the instantaneous opening area at the next time step.

#### **Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to `Include valve opening dynamics`.

### **Initial area — Opening area at the start of simulation**

$1\text{e-}12 \text{ m}^2$  (default) | positive scalar in units of area

Area normal to the direction of flow within the valve at the start of simulation. The block uses this parameter to calculate the initial rate at which the valve is opening and from it the instantaneous opening area at the next time step.

#### **Dependencies**

This parameter is active when the **Opening dynamics** block parameter is set to `Include valve opening dynamics`.

## **Version History**

Introduced in R2016a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Pressure Compensator | Pressure Reducing 3-Way Valve | Pressure Reducing Valve

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Pressure Relief Valve (IL)

Pressure-relief valve in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Pressure Control Valves



## Description

The Pressure Relief Valve (IL) block represents a pressure relief valve in an isothermal liquid network. The valve remains closed when the pressure is less than a specified value. When this pressure is met or surpassed, the valve opens. This set pressure is either a threshold pressure differential over the valve, between ports **A** and **B**, or between port **A** and atmospheric pressure. For pressure control based on another element in the fluid system, see the Pressure Compensator Valve (IL) block.

## Pressure Control

You can use a constant value or a physical signal to control the set pressure:

- When you set **Set pressure control** to **Controlled**, connect a pressure signal to port **Ps** and define the constant **Pressure regulation range**. The valve response will be triggered when  $P_{control}$ , the pressure differential between ports **A** and **B**, is greater than  $P_{set}$  and below  $P_{max}$ .  $P_{max}$  is the sum of  $P_{set}$  and the pressure regulation range.
- When you set **Set pressure control** to **Constant**, the valve opening is continuously regulated between  $P_{set}$  and  $P_{max}$ . There are two options for pressure regulation available in the **Opening pressure specification** parameter:  $P_{control}$  can be the pressure differential between ports **A** and **B** or the pressure differential between port **A** and atmospheric pressure. The opening area is then modeled by either linear or tabular parameterization. When the **Tabulated data** option is selected,  $P_{set}$  and  $P_{max}$  are the first and last parameters of the **Pressure differential vector**, respectively.

## Conservation of Mass

The block conserves mass through the valve such that

$$\dot{m}_A + \dot{m}_B = 0.$$

The block calculates the mass flow rate as

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\rho}}{\sqrt{PR_{loss} \left( 1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 \right) \left[ \Delta p^2 + \Delta p_{crit}^2 \right]^{1/4}}} \Delta p$$

where:

- $C_d$  is the **Discharge coefficient**.

- $A_{valve}$  is the instantaneous valve open area.
- $A_{port}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference  $p_A - p_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

The opening area  $A_{valve}$  is determined by the opening parameterization (for Constant valves only) and the valve opening dynamics.

### Opening Parameterization

When you set **Opening parameterization** to Linear - Area vs. pressure, the block calculates the opening area as

$$A_{valve} = \hat{p}(A_{max} - A_{leak}) + A_{leak},$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{max} - p_{set}}.$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{max}$ . For more information, see “Numerical Smoothing”.

When you set **Opening parameterization** to Tabulated data - Area vs. pressure,  $A_{leak}$  and  $A_{max}$  are the first and last parameters of the **Opening area vector**, respectively. The smoothed, normalized pressure is also used when the smoothing factor is nonzero with linear interpolation and nearest extrapolation.

When you set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure, the valve opens according to the user-provided tabulated data of volumetric flow rate and pressure differential between ports **A** and **B**.

Within the limits of the tabulated data, the block calculates the mass flow rate as:



$$\dot{m} = \bar{\rho}\dot{V},$$

where:

- $\dot{V}$  is the volumetric flow rate.
- $\bar{\rho}$  is the average fluid density.

When the simulation pressure falls below the first element of the **Pressure drop vector** parameter,  $\Delta p_{TLU}(1)$ , the block calculates the mass flow rate as:

$$\dot{m} = K_{Leak}\bar{\rho}\sqrt{\Delta p}.$$

$$K_{Leak} = \frac{V_{TLU}(1)}{\sqrt{|\Delta p_{TLU}(1)|}},$$

where  $V_{TLU}(1)$  is the first element of the **Volumetric flow rate vector** parameter.

When the simulation pressure rises above the last element of the **Pressure drop vector** parameter,  $\Delta p_{TLU}(end)$ , the block calculates the mass flow rate as

$$\dot{m} = K_{Max}\bar{\rho}\sqrt{\Delta p}$$

$$K_{Max} = \frac{V_{TLU}(end)}{\sqrt{|\Delta p_{TLU}(end)|}}$$

where  $V_{TLU}(end)$  is the last element of the **Volumetric flow rate vector** parameter.

### Opening Dynamics

When you set **Opening dynamics** to On, the block introduces lag in the flow response to the valve opening.  $A_{valve}$  becomes the dynamic opening area,  $A_{dyn}$ ; otherwise,  $A_{valve}$  is the steady-state opening area. The instantaneous change in dynamic opening area is calculated based on the **Opening time constant** parameter,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, the block sets **Opening dynamics** to Off.

Steady-state dynamics are set by the same parameterization as valve opening, and are based on the control pressure,  $p_{control}$ . A nonzero **Smoothing factor** can provide additional numerical stability when the orifice is in near-closed or near-open position.

### Faults

When faults are enabled, the valve open area becomes stuck at a specified value in response to one of these triggers:

- Simulation time — Faulting occurs at a specified time.
- Simulation behavior — Faulting occurs in response to an external trigger. This exposes port **Tr**.

Three fault options are available in the **Opening area when faulted** parameter:

- Closed — The valve freezes at its smallest value, depending on the **Opening parameterization** parameter:

- When you set **Opening parameterization** to Linear - Area vs. pressure, the valve area freezes at the **Leakage area** parameter.
- When you set **Opening parameterization** to Tabulated data - Area vs. pressure, the valve area freezes at the first element of the **Opening area vector** parameter.
- Open — The valve freezes at its largest value, depending on the **Opening parameterization** parameter:
  - When you set **Opening parameterization** to Linear - Area vs. pressure, the valve area freezes at the **Maximum opening area** parameter.
  - When you set **Orifice parameterization** to Tabulated data - Area vs. pressure, the valve area freezes at the last element of the **Opening area vector** parameter.
- Maintain last value — The valve area freezes at the valve open area when the trigger occurred.

Due to numerical smoothing at the extremes of the valve area, the minimum area applied is larger than the **Leakage area** parameter, and the maximum is smaller than the **Maximum orifice area** parameter, in proportion to the **Smoothing factor** parameter value.

Once triggered, the valve remains at the faulted area for the rest of the simulation.

When you set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure, the fault options are defined by the volumetric flow rate through the valve:

- Closed — The valve stops at the mass flow rate associated with the first elements of the **Volumetric flow rate vector** parameter and the **Pressure drop vector** parameter:

$$\dot{m} = K_{Leak} \bar{\rho} \sqrt{\Delta p}.$$

- Open — The valve stops at the mass flow rate associated with the last elements of the **Volumetric flow rate vector** parameter and the **Pressure drop vector** parameter:

$$\dot{m} = K_{Max} \bar{\rho} \sqrt{\Delta p}$$

- Maintain at last value — The valve stops at the mass flow rate and pressure differential when the trigger occurs:

$$\dot{m} = K_{Last} \bar{\rho} \sqrt{\Delta p},$$

where

$$K_{Last} = \frac{|\dot{m}|}{\bar{\rho} \sqrt{|\Delta p|}}.$$

### Predefined Parameterization

You can populate the block with pre-parameterized manufacturing data, which allows you to model a specific supplier component.

To load a predefined parameterization:

- 1 In the block dialog box, next to **Selected part**, click the "<click to select>" hyperlink next to **Selected part** in the block dialogue box settings.
- 2 The Block Parameterization Manager window opens. Select a part from the menu and click **Apply all**. You can narrow the choices using the **Manufacturer** drop down menu.

- 3 You can close the **Block Parameterization Manager** menu. The block now has the parameterization that you specified.
- 4 You can compare current parameter settings with a specific supplier component in the Block Parameterization Manager window by selecting a part and viewing the data in the **Compare selected part with block** section.

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**Note** Predefined block parameterizations use available data sources to supply parameter values. The block substitutes engineering judgement and simplifying assumptions for missing data. As a result, expect some deviation between simulated and actual physical behavior. To ensure accuracy, validate the simulated behavior against experimental data and refine your component models as necessary.

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To learn more, see “List of Pre-Parameterized Components”.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Entry or exit point to the valve.

#### **B – Liquid port**

isothermal liquid

Entry or exit point to the valve.

### Input

#### **Ps – Set pressure signal**

physical signal

Varying-signal set pressure for controlled valve operation.

### Dependencies

To enable this port, set **Set pressure control** to **Controlled**.

#### **Tr – External fault trigger**

physical signal

Physical signal port for an external fault trigger. Triggering occurs when the value is greater than 0.5. There is no unit associated with the trigger value.

### Dependencies

This port is visible when **Enable faults** is set to **On** and **Fault trigger** is set to **External**.

## Parameters

### Parameters

#### **Set pressure control – Valve operation method**

Constant (default) | Controlled

Valve operation method. A **Constant** valve opens linearly over a fixed pressure regulation range or in accordance with tabulated pressure and opening area data that you provide. A **Controlled** valve opens according to a variable set pressure signal at port **Ps** over a fixed pressure regulation range.

#### **Opening parameterization – Method of modeling constant valve opening or closing**

Linear - Area vs. pressure (default) | Tabulated data - Area vs. pressure |  
Tabulated data - Volumetric flow rate vs. pressure

Method of modeling valve opening or closing. The valve opening is either parametrized linearly or by a table of values that correlate area to pressure differential.

#### **Opening pressure specification – Pressure differential used for valve control**

Pressure differential (default) | Pressure at port A

Pressure differential used for the valve control. Selecting **Pressure differential** sets the pressure difference between port **A** and port **B** as the trigger for pressure control. Selecting **Pressure at port A** sets the gauge pressure at port **A**, or the difference between the pressure at port **A** and atmospheric pressure, as the trigger for pressure control.

#### **Set pressure (gauge) – Threshold pressure**

0.1 MPa (default) | positive scalar

Gauge pressure beyond which valve operation is triggered when the **Pressure control specification** is with respect to port **A**.

#### **Dependencies**

To enable this parameter, set **Set pressure control** to **Constant** and **Pressure control specification** to **Pressure at port A**.

#### **Set pressure differential – Threshold pressure**

0 MPa (default) | positive scalar

Pressure beyond which valve operation is triggered. This is the set pressure when the **Pressure control specification** is with respect to the pressure differential between ports **A** and **B**.

#### **Dependencies**

To enable this parameter, set **Set pressure control** to **Constant** and **Pressure control specification** to **Pressure differential**.

#### **Pressure regulation range – Valve operational pressure range**

0.1 MPa (default) | positive scalar

Operational pressure range of the valve. The pressure regulation range begins at the valve set pressure and the end of the range is the maximum valve operating pressure.

#### **Dependencies**

To enable this parameter, set

- **Set pressure control** to Controlled
- **Set pressure control** to Constant and **Opening parameterization** to Linear - Area vs. pressure

#### **Maximum opening area — Area of fully opened valve**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the valve in its fully open position.

#### **Dependencies**

To enable this parameter, set either:

- **Set pressure control** to Controlled
- **Set pressure control** to Constant and **Opening parameterization** to Linear - Area vs. pressure

#### **Leakage area — Valve gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

#### **Dependencies**

To enable this parameter, set either:

- **Set pressure control** to Controlled.
- **Set pressure control** to Constant and **Opening parameterization** to Linear - Area vs. pressure

#### **Opening pressure (gauge) vector — Differential pressure values for tabular parameterization**

[0.2 : 0.2 : 1.2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Opening area vector** parameter. The elements are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

#### **Dependencies**

To enable this parameter, set **Set pressure control** to Constant, **Opening parameterization** to Tabulated data - Area vs. pressure, and **Opening pressure specification** to Pressure differential..

#### **Pressure differential vector — Differential pressure values for tabular parameterization**

[0.2 : 0.2 : 1.2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Opening area vector** parameter. The elements are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant, and set

- **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure, or
- **Opening parameterization** to Tabulated data - Area vs. pressure and **Opening pressure specification** to Pressure differential.

**Volumetric flow rate vector – Vector of volumetric flow rate for tabulated data parameterization**

[1e-09, 3.6e-05, 8.9e-05, .00015, .00023, .00031] (default) | 1-by-*n* vector

Vector of volumetric flow rate values for the tabular parameterization of valve opening. This vector must have the same number of elements as the **Pressure drop vector** parameter. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Opening parameterization** to Tabulated data - Volumetric flow rate vs. pressure.

**Opening area vector – Valve opening areas for tabular parameterization**

[1e-10, 2e-06, 4e-06, 6e-06, 8e-06, 1e-05] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of valve opening areas for the tabular parameterization of the valve opening area. The vector elements must correspond one-to-one with the elements in the **Pressure differential vector** parameter. The elements are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Set pressure control** to Constant and **Opening parameterization** to Tabulated data - Area vs. pressure.

**Cross-sectional area at ports A and B – Area at valve entry or exit**

inf m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. These areas are used in the pressure-flow rate equation determining mass flow rate through the valve.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows. The default discharge coefficient for a valve in Simscape Fluids is 0.64.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure.

#### Pressure recovery — Whether to account for pressure increase in area expansions

Off (default) | On

Accounts for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area. This increase in pressure is not captured when **Pressure recovery** is set to Off.

#### Opening dynamics — Whether to account for flow response to valve opening

Off (default) | On

Whether to account for transient effects to the fluid system due to valve opening. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the flow response. The **Opening time constant** also impacts the modeled opening dynamics.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure.

#### Opening time constant — Valve opening time constant

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

#### Dependencies

To enable this parameter, set **Opening parameterization** to Linear - Area vs. pressure or Tabulated data - Area vs. pressure and **Opening dynamics** to On.

#### Faults

##### Enable faults — Fault option

Off (default) | On

Enable externally or temporally triggered faults. When faulting occurs, the valve area normally set by the opening parameterization will be set to the value specified in the **Opening area when faulted** parameter.

##### Opening area when faulted — Set faulted characteristics

Closed (default) | Open | Maintain last value

Sets the faulted valve type. You can choose for the valve to seize when the valve is opened, closed, or at the area when faulting is triggered.

#### Dependencies

To enable this parameter, set **Enable faults** to On.

**Fault trigger – External or temporal trigger option**

Temporal (default) | External

Whether a fault trigger occurs due to an external event or at a specified time.

When set to External, port **Tr** is enabled. A physical signal at port **Tr** that is greater than 0.5 triggers faulting.

When set to Temporal, when the **Simulation time for fault event** is reached, the valve area will be set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On.

**Simulation time for fault event – Time at which faulting is triggered**

5 s (default) | positive scalar

When the **Simulation time for fault event** is reached, the valve area is set to the value specified in the **Opening area when faulted** parameter.

**Dependencies**

To enable this parameter, set **Enable faults** to On and **Fault trigger** to Temporal.

## Version History

**Introduced in R2020a****Access pre-parameterized block options**

The block supports pre-parameterization options. Suppliers include Daikin, Kawasaki Heavy Industries, Parker, and Yuken.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Pressure Compensator Valve (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Pressure-Compensated Flow Control Valve (IL) | Check Valve (IL) | Counterbalance Valve (IL)



# Pressure Relief Valve (G)

Pressure relief valve in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Pressure Control Valves



## Description

The Pressure Relief Valve (G) block represents an orifice that opens with inlet pressure to keep the pressure from reaching extreme levels. At normal pressures, the valve is closed and only releases leakage flow. Above a specified pressure setting, the valve begins to open, which allows the gas to vent from the region of high pressure. The opening area increases with inlet pressure up to a maximum value, at which point the valve is fully open and pressure rises unabated.

The valve responds to inlet pressure relative to the outlet or inlet pressure relative to the environment. The chosen pressure measurement is the *control pressure* of the valve. The **Control pressure specification** parameter determines which of the measurements the block uses during simulation.

The relationship between the opening area and the pressure drop depends on the parameterization of the valve. That relationship can take the form of a linear analytical expression or a tabulated function.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

## Control and Other Pressures

The pressure at the inlet is the control signal of the valve. The more the inlet pressure rises over the pressure setting of the valve, the greater the opening area becomes. The inlet pressure measurement can be relative to the outlet or the environment. You can select the control pressure by setting the **Opening pressure specification** parameter to Pressure difference of port A relative to port B or Gauge pressure at port A. The term *control pressure* refers to both measurements.

### Pressure Difference of Port A Relative to Port B

When the **Opening pressure specification** parameter is Pressure difference of port A relative to port B:

- The control pressure is

$$P_{\text{Ctrl}} = P_A - P_B,$$

where  $P_A$  is the absolute pressure at port **A** and  $P_B$  is the absolute pressure at port **B**.

- The pressure setting,  $P_{Set}$ , is the value of the **Set pressure differential** parameter when the **Opening characteristic** parameter is **Linear**. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Set}$  is the first element of the **Opening pressure differential vector** parameter.
- When the **Opening characteristic** parameter is **Linear** and the valve is fully open, the maximum pressure of the valve,  $P_{Max}$ , is

$$P_{Max} = P_{Set} + \Delta P,$$

where  $\Delta P$  is the pressure regulation range of the valve. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Max}$  is the last element of the **Opening pressure differential vector** parameter.

### Gauge Pressure at Port A

When the **Opening pressure specification** parameter is **Gauge pressure at port A**:

- The control pressure is

$$P_{Ctl} = P_A - P_{Atm},$$

where  $P_{Atm}$  is the atmospheric pressure specified in the Gas Properties (G) block of the model.

- The pressure setting,  $P_{Set}$ , is the value of the **Set pressure (gauge)** parameter when the **Opening characteristic** parameter is **Linear**. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Set}$  is the first element of the **Opening pressure (gauge) vector** parameter.
- When the **Opening characteristic** parameter is **Linear** and the valve is fully open, the maximum pressure of the valve,  $P_{Max}$ , is

$$P_{Max} = P_{Set} + \Delta P,$$

where  $\Delta P$  is the pressure regulation range of the valve. When the **Opening characteristic** parameter is **Tabulated**,  $P_{Max}$  is the last element of the **Opening pressure (gauge) vector** parameter.

### Fraction of Valve Opening

The degree to which the control pressure exceeds the pressure setting determines how much the valve opens. When the **Opening characteristic** parameter is **Linear**, the block calculates the valve opening fraction to scale the flow characteristic parameters. The valve opening fraction is

$$\hat{p} = \frac{P_{Ctl} - P_{Set}}{\Delta P},$$

where:

- $P_{Ctl}$  is the control pressure.
- $P_{Set}$  is the pressure specified by the **Set pressure differential** or **Set pressure (gauge)** parameters.
- $\Delta P$  is the pressure regulation range specified by the **Pressure regulation range** parameter.

The fraction is normalized so that it is 0 in the fully closed valve and 1 in the fully open valve. If the calculation returns a value outside of these bounds, the block saturates the value to the nearest of the two limits.

### Numerical Smoothing

When the **Opening characteristic** parameter is Linear and the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the normalized control pressure,  $\hat{p}$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

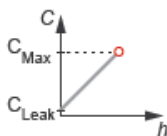
- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parametrization.

### Opening Characteristics

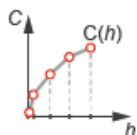
The flow characteristic relates the opening of the valve to the input that produces it. The opening is expressed as a sonic conductance, flow coefficient, or restriction area, determined by the **Valve parameterization** parameter.

The flow characteristic is normally given at steady state, with the inlet at a constant, carefully controlled pressure. The flow characteristic depends only on the valve and can be linear or nonlinear. To capture the flow characteristics, use the **Opening characteristic** parameter:

- **Linear** — The measure of flow capacity is a linear function of the valve opening fraction. As the opening fraction rises from 0 to 1, the measure of flow capacity scales from the specified minimum to the specified maximum.



- **Tabulated** — The measure of flow capacity is a general function, which can be linear or nonlinear, of the orifice opening fraction. The function is specified in tabulated form, with the independent variable specified by the **Opening pressure differential vector** or the **Opening pressure (gauge) vector**.



## Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to Cv flow coefficient parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.
- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3 p_{in} F_\gamma x_T},$$

where:

- $F_\gamma$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3 F_\gamma x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_\gamma x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3} C_v N_6 \sqrt{F_\gamma x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865 C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C\rho_{ref}p_{in}\sqrt{\frac{T_{ref}}{T_{in}}}\left[1 - \left(\frac{p_{out} - B_{crit}}{1 - B_{crit}}\right)^2\right]^m,$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.
- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ ,

$$\dot{m} = C\rho_{ref}\sqrt{\frac{T_{ref}}{T_{avg}}}\left[1 - \left(\frac{B_{lam} - B_{crit}}{1 - B_{crit}}\right)^2\right]^m\left(\frac{p_{in} - p_{out}}{1 - B_{lam}}\right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C\rho_{ref}p_{in}\sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma - 1} p_{in} \rho_{in} \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}} \left[ \frac{1 - \left(\frac{p_{out}}{p_{in}}\right)^{\frac{\gamma - 1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}}}\right]},$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma-1} \frac{2-\gamma}{p_{avg}^\gamma} \rho_{avg} \frac{2}{B_{lam}^\gamma} \left[ \frac{1 - B_{lam}^\gamma}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^\gamma} \right] \left( \frac{p_{in}^\gamma - p_{out}^\gamma}{1 - B_{lam}^\gamma} \right)}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Assumptions and Limitations

- The **Sonic** conductance setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice** area parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Conserving

#### A – Valve entrance

gas

Gas conserving port associated with the opening through which the flow must enter the valve.

#### B – Valve entrance

gas

Gas conserving port associated with the opening through which the flow must exit the valve.

## Parameters

### Opening pressure specification – Choice of pressure measurement to use as valve control signal

Pressure difference of port A relative to port B (default) | Gauge pressure at port A

Choice of pressure measurement to use as valve control signal. The block uses this setting to determine when the valve should begin to open. In the default setting, Pressure difference of port A relative to port B, the opening pressure of the valve is expressed as a pressure drop from inlet to outlet. In the alternative setting, Gauge pressure at port A, it is expressed as a gauge inlet pressure.

### Valve parameterization – Parameterization used to specify flow characteristics of valve

$C_v$  flow coefficient (default) |  $K_v$  flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- $C_v$  flow coefficient – The flow coefficient  $C_v$  determines the block parameterization.
- $K_v$  flow coefficient – The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- Sonic conductance – The sonic conductance of the resistive element at steady state determines the block parameterization.
- Orifice area – The size of the flow restriction determines the block parametrization.

### Opening characteristic – Method to calculate the opening characteristics of the valve

Linear (default) | Tabulated

Method the block uses to calculate the opening area of the valve. The linear setting treats the opening area as a linear function of the orifice opening fraction. The tabulated setting allows for a general, nonlinear relationship you can specify in tabulated form.

### Set pressure differential – Threshold differential for valve operation

0 MPa (default) | positive scalar

Pressure drop, from inlet to outlet, required to open the valve. This value marks the beginning of the pressure regulation range, over which the valve progressively opens in an effort to contain a pressure

rise. The opening area of the valve depends on the difference between the actual pressure drop to the value specified here.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to Pressure difference at port A relative to port B and **Opening characteristic** to Linear.

#### Pressure regulation range — Width of the pressure range over which the opening area is variable

0.1 MPa (default) | positive scalar

Width of the pressure range over which the opening area of the valve is variable. The pressure range begins at the set pressure measurement specified in the block: **Set pressure differential** or **Set pressure (gauge)**, depending on the setting of the **Opening pressure specification** parameter. It ends at the sum of the set pressure with the value specified here. The smaller the pressure regulation range, the faster the valve reaches its maximum opening area.

#### Dependencies

To enable this parameter, set **Opening characteristic** to Linear.

#### Set pressure (gauge) — Inlet gauge pressure required to open the valve

0.1 MPa (default) | positive scalar in units of pressure

Inlet gauge pressure required to open the valve. This parameter marks the beginning of the pressure regulation range, over which the valve progressively opens in an effort to contain a pressure rise. The opening area of the valve depends on the difference between the actual inlet pressure to the value specified here.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A and **Opening characteristic** to Linear.

#### Opening pressure differential vector — Vector of control pressures at which to specify valve opening data

0.2 : 0.2 : 1.2 MPa (default) | vector

Vector of control pressures at which to specify the chosen measure of valve opening—sonic conductance, flow coefficient, or opening area. This vector must be equal in size to those containing the valve opening data. The vector elements must be positive and increase monotonically from left to right. These pressure values are the pressure drop from inlet to outlet.

The first vector element gives the pressure setting of the valve, at which the valve begins to open. This element is equivalent to the **Set pressure differential** parameter of the Linear opening parameterizations. The last element gives the maximum pressure, at which the valve is fully open. The difference between the two gives the pressure regulation range of the valve.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to Pressure difference at port A relative to port B and **Opening characteristic** to Tabulated.

#### Opening pressure (gauge) vector — Vector of control pressures at which to specify valve opening data

0.2 : 0.2 : 1.2 MPa (default) | vector



Vector of control pressures at which to specify the chosen measure of valve opening—sonic conductance, flow coefficient, or opening area. This vector must be equal in size to those containing the valve opening data. The vector elements must be positive and increase monotonically in value from left to right. These pressures are the gauge pressure at the inlet.

The first vector element gives the pressure setting of the valve, at which the valve begins to open. This element is equivalent to the **Set pressure (gauge)** parameter of the **Linear** opening parameterizations. The last element gives the maximum pressure, at which the valve is fully open. The difference between the two gives the pressure regulation range of the valve.

#### Dependencies

To enable this parameter, set **Opening pressure specification** to Gauge pressure at port A and **Opening characteristic** to Tabulated.

#### Maximum $C_v$ flow coefficient — $C_v$ coefficient that corresponds to maximally open component

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

#### Dependencies

To enable this parameter, set **Valve parameterization** to  $C_v$  flow coefficient, and **Opening characteristic** to Linear.

#### xT pressure differential ratio factor at choked flow — Ratio of pressure differentials

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

#### Dependencies

To enable this parameter, set **Valve parameterization** to  $C_v$  flow coefficient or  $K_v$  flow coefficient.

#### Leakage flow fraction — Ratio of flow rates

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

#### Dependencies

To enable this parameter, set **Opening characteristic** to Linear.

#### Smoothing factor — Numerical smoothing factor

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Opening characteristic** to Linear.

**Cv flow coefficient vector – Cv coefficients corresponding to values in opening fraction vector**

[1e-06, .8, 1.6, 2.4, 3.2, 4] (default) | vector of positive numbers

Vector of  $C_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector**.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum Kv flow coefficient – Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Linear.

**Kv flow coefficient vector – Kv coefficients corresponding to values in opening fraction vector**

[1e-06, .72, 1.44, 2.16, 2.88, 3.6] (default) | vector of positive numbers

Vector of  $K_v$  flow coefficients. Each coefficient corresponds to a value in the **Opening fraction vector** parameter. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential. The flow coefficients must increase monotonically from left to right, with greater opening fractions representing greater flow coefficients. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient, and **Opening characteristic** to Tabulated.

**Maximum sonic conductance – Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance, and **Opening characteristic** to Linear.

**Subsonic index — Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference temperature — ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**ISO reference density — ISO 8778 reference density**1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Sonic conductance vector — Sonic conductances corresponding to values in opening fraction vector**

[1e-05, 2.4, 4.8, 7.2, 9.6, 12] 1/(bar\*s) (default) | vector of positive values

Vector of sonic conductances inside the resistive element. Each conductance corresponds to a value in the **Opening fraction vector** parameter. The sonic conductances must increase monotonically from left to right, with greater opening fractions representing greater sonic conductances. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance, and **Opening characteristic** to Tabulated.

**Critical pressure ratio vector — Critical pressure ratios corresponding to values in opening fraction vector**

0.3 \* ones(1,6) (default) | vector of positive numbers

Vector of critical pressure ratios at which the flow first chokes, with each critical pressure ratio corresponding to a value in the **Opening fraction vector** parameter. The critical pressure ratio is the fraction of downstream-to-upstream pressures at which the flow velocity reaches the local speed of sound. The size of the vector must be the same as the **Opening fraction vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`, and **Opening characteristic** to `Tabulated`.

**Maximum orifice area — Flow area corresponding to maximally open component**

$1e-4 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Linear`.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Orifice area vector — Vector of orifice opening area values**

[ $1e-10$ ,  $2e-05$ ,  $4e-05$ ,  $6e-05$ ,  $8e-05$ ,  $.0001$ ]  $\text{m}^2$  (default) | vector

Vector of cross-sectional areas of the orifice opening. The values in this vector correspond one-to-one with the elements in the **Opening fraction vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`, and **Opening characteristic** to `Tabulated`.

**Laminar flow pressure ratio — Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B — Flow area at gas ports**

$0.01 \text{ m}^2$  (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

Introduced in R2018b

### Model gas systems using improved flow computations

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.
- The **Pressure control specification** parameter has been renamed to **Opening pressure specification**. The options for this parameter have been renamed to **Pressure difference of port A relative to port B** and **Gauge pressure at port A**.
- The **Control pressure vector** parameter has been renamed to **Opening pressure differential vector** or **Opening pressure (gauge) vector**, depending on the choice for **Opening pressure specification**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Orifice (G) | Pressure Reducing Valve (G)

# Pressure Relief Valve (TL)

Pressure relief valve in a thermal liquid network

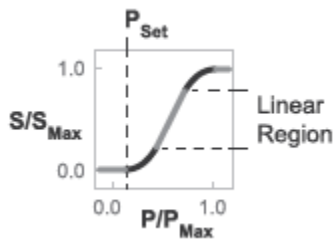
**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Pressure Control Valves



## Description

The Pressure Relief Valve (TL) block represents a valve that relieves excess pressure in a thermal liquid network. The valve allows flow through the networks and opens to relieve excess flow when the control pressure reaches the value of the **Valve set pressure (gauge)** parameter. A control pressure above the set pressure causes the valve to gradually open, which allows the fluid network to relieve excess pressure.

A smoothing function allows the valve opening area to change smoothly between the fully closed and fully open positions. The smoothing function removes the abrupt opening area changes at the zero and maximum opening positions. The figure shows the effect of smoothing on the valve opening area curve.



## Mass Balance

The mass conservation equation in the valve is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate into the valve through port **A**.
- $\dot{m}_B$  is the mass flow rate into the valve through port **B**.

## Momentum Balance

The momentum conservation equation in the valve is

$$p_A - p_B = \frac{\dot{m}\sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{2\rho_{Avg}C_d^2S^2} \left[ 1 - \left( \frac{S_R}{S} \right)^2 \right] PR_{Loss},$$

where:

- $p_A$  and  $p_B$  are the pressures at port **A** and port **B**.
- $\dot{m}$  is the mass flow rate.
- $\dot{m}_{cr}$  is the critical mass flow rate.
- $\rho_{Avg}$  is the average liquid density.
- $C_d$  is the discharge coefficient.
- $S_R$  is the valve opening area.
- $S$  is the valve inlet area.
- $PR_{Loss}$  is the pressure ratio:

$$PR_{Loss} = \frac{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} - C_d(S_R/S)}{\sqrt{1 - (S_R/S)^2(1 - C_d^2)} + C_d(S_R/S)}$$

The block computes the valve opening as

$$S_R = \hat{p}_{smoothed} \cdot (S_{Max} - S_{Leak}) + S_{Leak}$$

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{Max} - p_{set}}$$

where:

- $S_{Leak}$  is the valve leakage area.
- $S_{Max}$  is the maximum valve opening area.
- $p_{control}$  is the valve control pressure:

$$p_{control} = \begin{cases} p_A, & \text{Pressure at port A} \\ p_A - p_B, & \text{Pressure differential} \end{cases}$$

- $p_{set}$  is the valve set pressure:

$$p_{set} = \begin{cases} p_{set, gauge} + p_{Atm}, & \text{Pressure at port A} \\ p_{set, diff}, & \text{Pressure differential} \end{cases}$$

- $p_{Max}$  is the maximum pressure:

$$p_{max} = \begin{cases} p_{set, gauge} + p_{range} + p_{Atm}, & \text{Pressure at port A} \\ p_{set, diff} + p_{range}, & \text{Pressure differential} \end{cases}$$

where the two equations refer to the settings of the **Pressure control specification** parameter.

The critical mass flow rate is

$$\dot{m}_{cr} = Re_{cr} \mu_{Avg} \sqrt{\frac{\pi}{4}} S_R$$

### Numerically-Smoothed Valve Area

When the valve is in a near-open or near-closed position, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter



is nonzero, the block smoothly saturates the control pressure between  $p_{set}$  and  $p_{Max}$ . For more information, see “Numerical Smoothing”.

## Energy Balance

The energy conservation equation in the valve is

$$\phi_A + \phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate into the valve through port **A**.
- $\phi_B$  is the energy flow rate into the valve through port **B**.

## Ports

### Conserving

#### **A — Liquid port**

thermal liquid

Thermal liquid conserving port associated with valve inlet A.

#### **B — Liquid port**

thermal liquid

Thermal liquid conserving port associated with valve inlet B.

## Parameters

### **Pressure control specification — Method to evaluate pressure**

Pressure at port A (default) | Pressure differential

Specification method for the valve control pressure. When you select **Pressure at port A**, the block only uses the pressure at port **A** to determine when the flow exceeds the value of the **Valve set pressure (gauge)** parameter. When you select **Pressure differential**, the block uses the value of the **Valve set pressure differential** parameter to determine whether the pressure differential from port **A** to port **B** exceeds the range.

### **Valve set pressure (gauge) — Gauge pressure beyond which valve operation triggers**

0.1 MPa (default) | positive scalar

Pressure at which the opening mechanism triggers. The opening area remains variable throughout the pressure regulation range of the valve.

### Dependencies

To enable this parameter, set **Pressure control specification** to **Pressure** pressure at port A.

### **Valve set pressure differential — Minimum opening pressure differential**

0 MPa (default) | nonnegative scalar

Minimum pressure differential between ports **A** and **B** required to open the valve. A pressure differential above this value causes the valve to gradually open until it reaches the fully open state.

**Dependencies**

To enable this parameter, set **Pressure control specification** to Pressure differential.

**Pressure regulation range — Valve pressure range**

0.01 MPa (default) | positive scalar

Pressure interval over which the valve opening area varies. The interval begins at the value of the **Valve set pressure (gauge)** or once the difference between ports **A** and **B** exceeds the value of the **Valve set pressure differential** parameter.

**Maximum opening area — Opening area in the fully open position due to sealing imperfections**

$1e-4 \text{ m}^2$  (default) | positive scalar

Opening area of the valve in the fully open position, when the valve is at the upper limit of the pressure regulation range.

**Leakage area — Gap area when in fully shut position**

$1e-12 \text{ m}^2$  (default) | positive scalar

Sum of all gaps when the valve is in the fully shut position. The block saturates smaller numbers to this value. This parameter contributes to numerical stability by maintaining continuity in the flow.

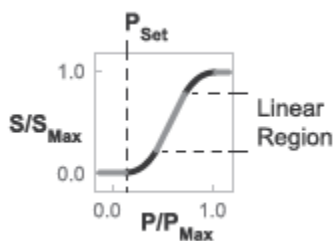
**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

A smoothing factor of 0 corresponds to a linear function that is discontinuous at the set and maximum-area pressures. A smoothing factor of 1 corresponds to a nonlinear function that changes continuously throughout the entire function domain.

A smoothing factor between 0 and 1 corresponds to a continuous function with smooth nonlinear transitions at the set and maximum-area pressures. The figure shows the smoothing regions.

**Cross-sectional area at ports A and B — Area at conserving ports**

$0.01 \text{ m}^2$  (default) | positive scalar

Area at ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient — Discharge coefficient**

0.7 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## **Version History**

**Introduced in R2016a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Pressure Reducing Valve (TL)

## Pressure Relief Valve (2P)

Pressure relief valve in a two-phase fluid network

**Library:** Simscape / Fluids / Two-Phase Fluid / Valves & Orifices / Pressure Control Valves



### Description

The Pressure Relief Valve (2P) block models a pressure-controlling relief valve in a two-phase fluid network. The valve opens when the pressure exceeds the set pressure. Specify the pressure differential that opens the valve in the **Set pressure specification** parameter, which can be the pressure difference between ports **A** and **B** or the gauge pressure at port **A**. When you set **Set pressure control** to **Controlled**, the set pressure varies according to the input signal at port **Ps**.

Fluid properties inside the valve are calculated from inlet conditions. There is no heat exchange between the fluid and the environment, and therefore phase change inside the valve only occurs due to a pressure drop or a propagated phase change from another part of the model.

A number of block parameters are based on nominal operating conditions, which correspond to the valve rated performance, such as a specification on a manufacturer datasheet.

### Pressure Control

The valve opens when the pressure in the valve,  $p_{control}$ , exceeds the **Set pressure differential**,  $p_{set}$ . The valve is fully open when the control pressure reaches the end of the **Pressure regulation range**,  $p_{range}$ .

When you set **Set pressure control** to **Constant**, the opening fraction of the valve,  $\lambda$ , is expressed as:

$$\lambda = (1 - f_{leak}) \frac{(p_{control} - p_{set})}{p_{range}} + f_{leak},$$

where:

- $f_{leak}$  is the **Closed valve leakage as a fraction of nominal flow**.
- $p_{control}$  is the control pressure, which depends on the **Set pressure specification** parameter.

When you set **Set pressure specification** to **Pressure differential**, the control pressure is  $P_A - p_B$ .

When you set **Set pressure specification** to **Gauge pressure at port A**, the control pressure is the difference between the pressure at port **A** and atmospheric pressure.

When you set **Set pressure control** to **Controlled**, the valve opening fraction is:

$$\lambda = (1 - f_{leak}) \frac{(p_{control} - p_s)}{p_{range}} + f_{leak},$$

where  $p_s$  is the signal at port **Ps**. If the control pressure exceeds the valve pressure regulation range, the valve opening fraction is 1.

### Mass Flow Rate

The mass flow rate depends on the pressure differential, and therefore the open area of the valve. It is calculated as:

$$\dot{m}_A = \lambda \dot{m}_{nom} \left[ \sqrt{\frac{v_{nom}}{2\Delta p_{nom}}} \right] \sqrt{\frac{2}{v_{in} (\Delta p^2 + \Delta p_{lam}^2)^{0.25}}}$$

where:

- $\Delta p$  is the pressure drop over the valve,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure transition threshold between laminar and turbulent flow, which is calculated from the **Laminar flow pressure ratio**,  $B_{lam}$ :

$$\Delta p_{lam} = \frac{(p_A + p_B)}{2} (1 - B_{lam}).$$

- $\dot{m}_{nom}$  is the **Nominal mass flow rate at maximum opening**.
- $\Delta p_{nom}$  is the **Nominal pressure drop rate at maximum opening**.
- $v_{nom}$  is the nominal inlet specific volume. This value is determined from the fluid properties tabulated data based on the **Nominal inlet specific enthalpy** and **Nominal inlet pressure** parameters.
- $v_{in}$  is the inlet specific volume.

### Fluid Specific Volume Dynamics

When the fluid at the valve inlet is a liquid-vapor mixture, the block calculates the specific volume as:

$$v_{in} = (1 - x_{dyn})v_{liq} + x_{dyn}v_{vap}$$

where:

- $x_{dyn}$  is the inlet vapor quality. The block applies a first-order lag to the inlet vapor quality of the mixture.
- $v_{liq}$  is the liquid specific volume of the fluid.
- $v_{vap}$  is the vapor specific volume of the fluid.

If the inlet fluid is liquid or vapor,  $v_{in}$  is the respective liquid or vapor specific volume.

### Vapor Quality Lag

If the inlet vapor quality is a liquid-vapor mixture, a first-order time lag is applied:

$$\frac{dx_{dyn}}{dt} = \frac{x_{in} - x_{dyn}}{\tau},$$

where:

- $x_{dyn}$  is the dynamic vapor quality.
- $x_{in}$  is the current inlet vapor quality.

- $\tau$  is the **Inlet phase change time constant**.

If the inlet fluid is a subcooled liquid or superheated vapor,  $x_{dyn}$  is equal to  $x_{in}$ .

### Mass Balance

Mass is conserved in the valve:

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

### Energy Balance

Energy is conserved in the valve:

$$\Phi_A + \Phi_B = 0,$$

where:

- $\Phi_A$  is the energy flow at port **A**.
- $\Phi_B$  is the energy flow at port **B**.

### Assumptions and Limitations

- The block does not model pressure recovery downstream of the valve.
- There is no heat exchange between the valve and the environment.
- The block does not model choked flow.

## Ports

### Conserving

#### **A — Fluid port**

two-phase fluid

Fluid entry or exit port.

#### **B — Fluid port**

two-phase fluid

Fluid entry or exit port.

### Input

#### **Ps — Set pressure**

physical signal

Input port for varying set pressure signal.

**Dependencies**

To enable this port, set **Set pressure control** to **Controlled**.

**Parameters****Set pressure control – Variable or constant set pressure**

Constant (default) | Controlled

Whether the pressure threshold is constant or variable. Setting this parameter to **Controlled** exposes the physical signal port **Ps**.

**Set pressure specification – Control pressure**

Pressure differential (default) | Gauge pressure at port A

Control pressure specification:

- When set to **Pressure differential**, the valve opens when  $p_A - p_B$  exceeds the **Set pressure differential**.
- When set to **Gauge pressure at port A**, the valve opens when  $p_A - p_{atm}$  exceeds the **Set pressure (gauge)**.

**Set pressure differential – Set pressure**

0.01 MPa (default) | positive scalar

Valve pressure threshold. When the control pressure,  $p_A - p_B$ , exceeds the set pressure, the valve begins to open.

**Dependencies**

To enable this parameter, set **Set pressure control** to **Constant** and **Set pressure specification** to **Pressure differential**.

**Set pressure (gauge) – Set pressure**

0.1 MPa (default) | positive scalar

Valve pressure threshold. When the control pressure,  $p_A - p_{atm}$ , exceeds the set pressure, the valve begins to open.

**Dependencies**

To enable this parameter, set **Set pressure control** to **Constant** and **Set pressure specification** to **Gauge pressure at port A**.

**Pressure regulation range – Valve operational range**

0.1 MPa (default) | positive scalar

Valve operational range. The valve begins to open at the set pressure value, and is fully open at  $p_{max}$ , the end of the pressure regulation range:  $p_{max} = p_{set} + p_{range}$ .

**Nominal mass flow rate at maximum opening – Rated mass flow rate**

0.1 kg/s (default) | positive scalar

Mass flow rate through a fully open valve under typical, design, or rated conditions.

**Nominal pressure drop at maximum opening — Rated pressure drop**

0.001 MPa (default) | positive scalar

Pressure drop over a fully open valve under typical, design, or rated conditions.

**Nominal inlet condition specification — Method of determining inlet fluid state**

Temperature (default) | Vapor quality | Vapor void fraction | Specific enthalpy | Specific internal energy

Method of determining inlet fluid state. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet pressure — Pressure of fluid entering valve**

0.101325 MPa (default) | positive scalar

Inlet pressure to the valve in typical, design, or rated conditions. The valve inlet specific volume is determined from the fluid properties tabulated data based on the **Nominal inlet pressure** and the setting of the **Nominal inlet condition specification** parameters.

**Nominal inlet temperature — Fluid temperature**

293.15 K (default) | positive scalar

Inlet fluid temperature in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Inlet vapor quality by mass fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet vapor quality of the mixture by mass fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor quality.

**Nominal inlet vapor void fraction — Inlet volume fraction**

0.5 (default) | positive scalar in the range [0,1]

Inlet mixture by volume fraction in nominal operating conditions. A value of 0 means that the inlet fluid is subcooled liquid. A value of 1 means that the inlet fluid is superheated vapor.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Vapor void fraction.

**Nominal inlet specific enthalpy — Inlet fluid specific enthalpy**

1500 kJ/kg (default) | positive scalar

Inlet specific enthalpy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific enthalpy.



**Nominal inlet specific internal energy — Inlet specific internal energy**

1500 kJ/kg (default) | positive scalar

Inlet specific internal energy in nominal operating conditions.

**Dependencies**

To enable this parameter, set **Nominal inlet condition specification** to Specific internal energy.

**Cross-sectional area at ports A and B — Valve port areas**0.01 m<sup>2</sup> (default) | positive scalar

Area of the valve ports **A** and **B**.

**Closed valve leakage as a fraction of nominal flow — Fractional flow when valve is closed**

1e-6 (default) | positive scalar

Fractional flow rate through the valve when it is fully closed. This parameter contributes to numerical stability by maintaining continuity in the fluid network.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio — Laminar-turbulent transition pressure ratio**

0.999 (default) | positive scalar

Ratio of the valve outlet pressure to valve inlet pressure at which the fluid transitions between the laminar and turbulent regimes. The pressure loss corresponds to the mass flow rate linearly in laminar flows and quadratically in turbulent flows.

**Inlet phase change time constant — Lag for mixture specific volume**

0.1 s (default) | positive scalar

Time lag for liquid-vapor mixtures in computing the fluid specific volume. This parameter does not influence the specific volume when the inlet fluid is a fully supercooled liquid or fully superheated vapor.

**Version History**

Introduced in R2021a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Pressure-Reducing Valve (2P) | Check Valve (2P) | Orifice (2P) | Thermostatic Expansion Valve (2P)

# Proportional and Servo-Valve Actuator

Continuous valve driver with output proportional to input signal



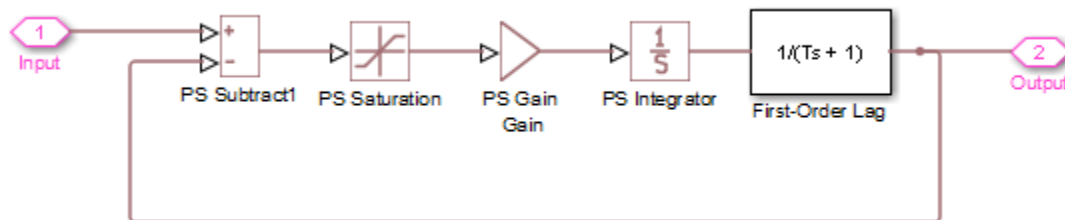
## Library

Valve Actuators

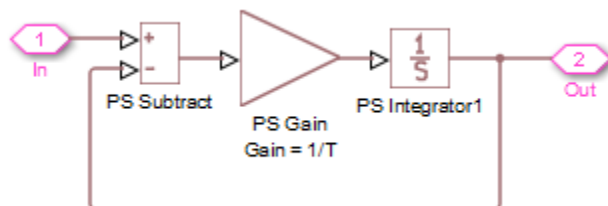
## Description

The Proportional and Servo-Valve Actuator block represents an electromagnetic actuator that is used in proportional and servo-valves to drive a spool or other working member. The block is intended to work with one of the directional valve models to form a desirable configuration of a proportional or servo-valve. The block is implemented as a data-sheet-based model and reproduces only the input/output relationship, or the actuator's transient response, as presented in the catalog or data sheet.

The Proportional and Servo-Valve Actuator block is built using the blocks from the Simscape Physical Signals library. Both the input and the output of the block are physical signals. The block diagram of the model is shown in the following figure.



The model of the actuator is built of the Foundation Library Physical Signals blocks: PS Subtract, PS Saturation, PS Gain, PS Integrator. The first-order lag is arranged as a subsystem, as shown below,

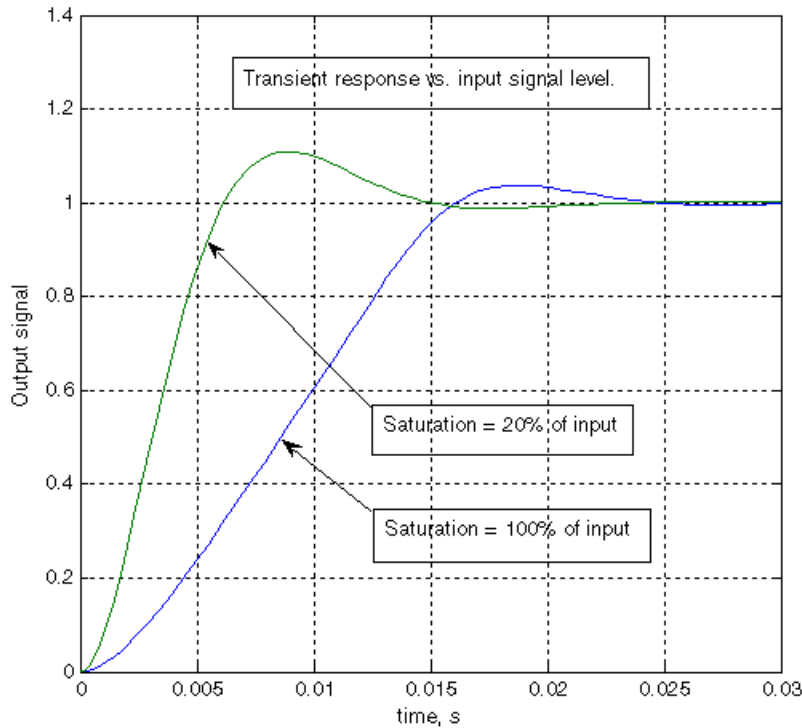


and is also built of the Physical Signals blocks: PS Subtract, PS Gain, and PS Integrator. The transfer function of the lag is

$$H(s) = \frac{1}{Ts + 1}$$

where  $T$  is the **Time constant** of the lag. The value of this parameter is set through the parameter **Gain** of the PS Gain block in the First-Order Lag subsystem by setting it equal to  $1/T$ .

The typical transient responses of a servo-valve or a high-quality proportional valve are shown in the following figure. The only difference between the two responses in the figure is the value of the saturation.



You can adjust the block parameters, such as saturation, gain, and time constant, to make the transient responses close enough to those provided in the data sheet. The most effective way to adjust the parameters is to use the Simulink Design Optimization software.

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**Note** This block is constructed out of blocks from the Simscape Physical Signals library (such as PS Add, PS Gain, and so on). Currently, the blocks in the Physical Signals library do not support unit propagation and checking. For more information, see “How to Work with Physical Units”.

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## Parameters

### Gain

Gain of the PS Gain block in the top level of the block diagram of the actuator model. The default value is 377.

### Time constant

Time constant of the first-order lag. The **Gain** parameter of the PS Gain block in the First-Order Lag subsystem is equal to  $1/\text{Time constant}$ . The default value is 0.002 s.

### Saturation

Saturation level of the PS Saturation block in the actuator model. The default value is 0.3.

## Ports

The block has one physical signal input port and one physical signal output port.

## Examples

The “Closed-Loop Actuator with Variable-Displacement Pressure-Compensated Pump” example illustrates the use of the Proportional and Servo-Valve Actuator block in hydraulic systems.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

2-Position Valve Actuator | 3-Position Valve Actuator | Hydraulic Double-Acting Valve Actuator | Hydraulic Single-Acting Valve Actuator

# Proportional Valve Actuator

Power-controlled valve actuator in any fluid domain

**Library:** Simscape / Fluids / Fluid Network Interfaces / Actuators



## Description

The Proportional Valve Actuator block models a power-controlled actuator used in conjunction with a valve block in any in any fluid domain. You can use it in combination with any valve block that takes a physical signal as input. The signal to open or close the valve is received at port **A**. The opening distance for a connected valve is returned as a physical signal at port **S**.

You can adjust the opening or closing magnitude with the **Actuator gain** parameter. A first-order lag in time is applied to the actuation distance:

$$\frac{(IG - d)}{\tau},$$

where:

- $IG$  is the signal received at port **A** multiplied by the **Actuator gain**. Outside of the valve stroke limits,  $IG$  is the **Valve stroke** if fully extended and the negative **Valve stroke** if fully retracted.
- $d$  is the current actuator position.
- $\tau$  is the **Time constant**.

## Ports

### Input

#### **A** – Valve opening signal

physical signal

Physical signal that indicates valve opening or closing, specified as a physical signal. The signal is multiplied by the **Actuator gain** value.

### Output

#### **S** – Valve opening distance, m

physical signal

Opening distance for the connected valve, in m, specified as a physical signal.

If you use the Proportional Valve Actuator block with a valve from the Gas Library, the gas block converts the actuator signal units of m to units of 1.

## Parameters

### **Actuator gain — Input signal multiplier**

5e-4 m (default) | positive scalar

Input signal multiplier for the valve opening distance.

### **Time constant — Opening signal time constant**

0.01 s (default) | positive scalar

Constant that captures the time required to reach steady-state conditions during actuation. This parameter impacts the response lag to the valve opening or closing signal.

### **Valve stroke — Maximum valve opening distance**

0.005 m (default) | positive scalar

Maximum opening distance of the connected valve.

## Version History

**Introduced in R2020a**

## Extended Capabilities

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

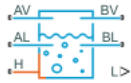
### **See Also**

Multiposition Valve Actuator | Pilot Valve Actuator (IL) | Cartridge Valve Actuator (IL)

## Receiver Accumulator (2P)

Tank with liquid and vapor volumes of variable proportion

**Library:** Simscape / Fluids / Two-Phase Fluid / Tanks & Accumulators



### Description

The Receiver-Accumulator (2P) block represents a tank with fluid that can undergo phase change. The liquid and vapor phases, referred to as *zones*, are modeled as distinct volumes that can change in size during simulation, but do not mix. The relative amount of space a zone occupies in the system is called a *zone fraction*, which ranges from 0 to 1. The vapor-liquid mixture phase is not modeled.

In an HVAC system, when this tank is placed between a condenser and an expansion valve, it acts as a receiver. Liquid connections to the block are made at ports **AL** and **BL**. When the tank is placed between an evaporator and a compressor, it acts as an accumulator. Vapor connections to the block are made at ports **AV** and **BV**. A fluid of either phase can be connected to either port, however the fluid exiting from a V port is in the vapor zone and an L port is in the liquid zone. There is no mass flow through unconnected ports.

The temperature of the tank walls are set at port **H**.

The liquid level of the tank is reported as a zone fraction at port **L**. If the liquid level reports 0, the tank is fully filled with vapor. The tank is never empty.

### Heat Transfer

The total heat transfer,  $Q_H$ , is the sum of the heat transfer in the liquid and vapor phases:

$$Q_H = Q_L + Q_V.$$

The heat transfer between the liquid and the wall is:

$$Q_L = (S_c + z_L S_s) \alpha_L (T_H - T_L) + S_c \alpha_{LV} (T_V - T_L)$$

where:

- $z_L$  is the liquid volume fraction of the tank.
- $S_c$  is the **Tank cross sectional area** parameter.
- $S_s$  is surface area of the tank side, which the block calculates from the volume and tank cross-sectional area.
- $\alpha_L$  is the **Liquid heat transfer coefficient** parameter.
- $T_H$  is the temperature of the tank wall.
- $T_L$  is the temperature of the liquid.

The block calculates the heat transfer coefficient between the liquid and the vapor as

$$\alpha_{LV} = \frac{1}{\frac{1}{\alpha_L} + \frac{1}{\alpha_V}}.$$



The heat transfer between the vapor and the wall is:

$$Q_V = (S_c + (1 - z_L)S_s)\alpha_V(T_H - T_V) + S_c\alpha_{LV}(T_L - T_V),$$

where:

- $\alpha_V$  is the **Vapor heat transfer coefficient**.
- $T_V$  is the temperature of the vapor.

The liquid volume fraction is determined from the liquid mass fraction:

$$z_L = \frac{f_{M,L}\nu_L}{f_{M,L}\nu_L + (1 - f_{M,L})\nu_V},$$

where:

- $f_{M,L}$  is the mass fraction of the liquid.
- $\nu_L$  is the specific volume of the liquid.
- $\nu_V$  is the specific volume of the vapor.

### Energy Flow Rates Due To Phase Change

When the liquid specific enthalpy is greater than or equal to the saturated liquid specific enthalpy, the mass flow rate of the vaporizing fluid is:

$$\dot{m}_{\text{Vap}} = \frac{M_L(h_L - h_{L,Sat})/(h_V - h_{L,Sat})}{\tau}.$$

where:

- $M_L$  is the total liquid mass.
- $\tau$  is the **Vaporization and condensation time constant** parameter.
- $h_L$  is the specific enthalpy of the liquid at the internal node.
- $h_{L,Sat}$  is the saturated liquid specific enthalpy at the internal node.
- $h_V$  is the specific enthalpy of the vapor.
- $h_{V,Sat}$  is the saturated vapor specific enthalpy.

The energy flow associated with vaporization is:

$$\phi_{\text{Vap}} = \dot{m}_{\text{Vap}}h_{V,Sat},$$

When the liquid specific enthalpy is lower than the saturated liquid specific enthalpy, no vaporization occurs, and  $\dot{m}_{\text{Vap}} = 0$ .

Similarly, when the vapor specific enthalpy is less than or equal to the saturated vapor specific enthalpy, the mass flow rate of the condensing fluid is:

$$\dot{m}_{\text{Con}} = \frac{M_V(h_V - h_{V,Sat})/(h_V - h_{L,Sat})}{\tau}.$$

where  $M_V$  is the total vapor mass.

The energy flow associated with condensation is:

$$\phi_{\text{Con}} = \dot{m}_{\text{Con}} h_{L, \text{Sat}},$$

When the vapor specific enthalpy is higher than the saturated vapor specific enthalpy, no condensation occurs, and  $\dot{m}_{\text{Con}} = 0$ .

### Mass Balance

The total tank volume is constant. Due to phase change, the volume fraction and mass of the fluid changes. The mass balance in the liquid zone is:

$$\frac{dM_L}{dt} = \dot{m}_{L, \text{In}} - \dot{m}_{L, \text{Out}} + \dot{m}_{\text{Con}} - \dot{m}_{\text{Vap}},$$

where:

- $\dot{m}_{L, \text{In}}$  is the inlet liquid mass flow rate at all L and V ports.
- $\dot{m}_{L, \text{Out}}$  is the outlet liquid mass flow rate:

$$\dot{m}_{L, \text{Out}} = -(\dot{m}_{\text{AL}} + \dot{m}_{\text{BL}}),$$

- $\dot{m}_{\text{Con}}$  is the mass flow rate of the condensing fluid.
- $\dot{m}_{\text{Vap}}$  is the mass flow rate of the vaporizing fluid.

The mass balance in the vapor zone is:

$$\frac{dM_V}{dt} = \dot{m}_{V, \text{In}} - \dot{m}_{V, \text{Out}} - \dot{m}_{\text{Con}} + \dot{m}_{\text{Vap}},$$

where:

- $M_V$  is the total vapor mass.
- $\dot{m}_{V, \text{In}}$  is the inlet vapor mass flow rate at all L and V ports.
- $\dot{m}_{V, \text{Out}}$  is the outlet vapor mass flow rate:

$$\dot{m}_{V, \text{Out}} = -(\dot{m}_{\text{AV}} + \dot{m}_{\text{BV}}).$$

If there is only one zone present in the tank, the outlet mass flow rate of the fluid is the sum of the flow rate through all of the ports:

$$\dot{m}_{\text{phase, Out}} = -(\dot{m}_{\text{AL}} + \dot{m}_{\text{BL}} + \dot{m}_{\text{AV}} + \dot{m}_{\text{BV}}).$$

where  $\dot{m}_{\text{phase, Out}}$  is  $\dot{m}_{L, \text{Out}}$  if the fluid is entirely liquid, and  $\dot{m}_{V, \text{Out}}$  if the fluid is entirely vapor.

### Energy Balance

The fluid can heat or cool depending on the heat transfer between the tank and wall, which is set by the temperature at port **H**.

The energy balance in the liquid zone is:

$$M_L \frac{du_L}{dt} + \frac{dM_L}{dt} u_L = \phi_{L, \text{In}} - \phi_{L, \text{Out}} + \phi_{\text{Con}} - \phi_{\text{Vap}} + Q_L.$$

where:

- $u_L$  is the specific internal energy of the liquid.
- $\phi_{L,In}$  is the inlet liquid energy flow rate at all L and V ports.
- $\phi_{L,Out}$  is the outlet liquid energy flow rate:  

$$\phi_{L,Out} = -(\phi_{AL} + \phi_{BL}).$$
- $\phi_{Con}$  is the energy flow rate of the condensing vapor.
- $\phi_{Vap}$  is the energy flow rate of the vaporizing liquid.
- $Q_L$  is the heat transfer between the tank wall and the liquid.

The energy balance in the vapor zone is:

$$M_V \frac{du_V}{dt} + \frac{dM_V}{dt} u_V = \phi_{V,In} - \phi_{V,Out} - \phi_{Con} + \phi_{Vap} + Q_V.$$

- $u_V$  is the specific internal energy of the vapor.
- $\phi_{V,In}$  is the inlet vapor energy flow rate at all L and V ports.
- $\phi_{V,Out}$  is the outlet vapor energy flow rate:  

$$\phi_{V,Out} = -(\phi_{AV} + \phi_{BV}).$$
- $Q_V$  is the heat transfer between the tank wall and the vapor.

If there is only one zone present in the tank, the outlet energy flow rate is the sum of the flow rate through all of the ports:

$$\phi_{phase,Out} = -(\phi_{AL} + \phi_{BL} + \phi_{AV} + \phi_{BV}).$$

where  $\phi_{phase,Out}$  is  $\phi_{L,Out}$  if the fluid is entirely liquid, and  $\phi_{V,Out}$  if the fluid is entirely vapor.

### Momentum Balance

There are no pressure changes modeled in the tank, including hydrostatic pressure. The pressure at any port is equal to the internal tank pressure.

### Assumptions and Limitations

- Pressure must remain below the critical pressure.
- Hydrostatic pressure is not modeled.
- The container wall is rigid, therefore the total volume of fluid is constant.
- The thermal mass of the tank wall is not modeled.
- Flow resistance through the outlets is not modeled. To model pressure losses associated with the outlets, connect a Local Restriction (2P) block or a Flow Resistance (2P) block to the ports of the Receiver-Accumulator (2P) block.
- A liquid-vapor mixture is not modeled.

## Ports

### Output

#### L – Liquid level

physical signal

Liquid level in the tank. Use this port to monitor the amount of liquid remaining inside.

### **Conserving**

#### **AV — Tank opening**

two-phase fluid

Opening for the fluid to flow into or out of the tank. Both liquid and vapor can enter through this port. However, only vapor can exit through it—until the tank is depleted of vapor, in which event liquid too can flow out through this port.

#### **BV — Tank opening**

two-phase fluid

Opening for the fluid to flow into or out of the tank. Both liquid and vapor can enter through this port. However, only vapor can exit through it—until the tank is depleted of vapor, in which event liquid too can flow out through this port.

#### **AL — Tank opening**

two-phase fluid

Opening for the fluid to flow into or out of the tank. Both liquid and vapor can enter through this port. However, only liquid can exit through it—until the tank is depleted of liquid, in which event vapor too can flow out through this port.

#### **BL — Tank opening**

two-phase fluid

Opening for the fluid to flow into or out of the tank. Both liquid and vapor can enter through this port. However, only liquid can exit through it—until the tank is depleted of liquid, in which event vapor too can flow out through this port.

#### **H — Tank wall**

thermal

Thermal boundary between the fluid volume and the tank wall. Use this port to capture heat exchanges of various kinds—for example, conductive, convective, or radiative—between the fluid and the environment external to the tank.

## **Parameters**

### **Main**

#### **Total tank volume — Aggregate volume of liquid and vapor phases in the tank**

1 m<sup>3</sup> (default) | positive scalar

Aggregate volume of liquid and vapor phases in the tank.

#### **Tank cross-sectional area — Tank cross-sectional area**

0.5 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the tank.

#### **Cross-sectional area at port AV — Area normal to the direction of flow at port AV**

0.01 m<sup>2</sup> (default) | positive scalar with units of area

Area normal to the direction of flow at port **AV**.

**Cross-sectional area at port BV — Area normal to the direction of flow at port BV**  
 0.01 m<sup>2</sup> (default) | positive scalar with units of area

Area normal to the direction of flow at port **BV**.

**Cross-sectional area at port AL — Area normal to the direction of flow at port AL**  
 0.01 m<sup>2</sup> (default) | positive scalar with units of area

Area normal to the direction of flow at port **AL**.

**Cross-sectional area at port BL — Area normal to the direction of flow at port BL**  
 0.01 m<sup>2</sup> (default) | positive scalar with units of area

Area normal to the direction of flow at port **BL**.

**Liquid volume fraction out of range — Means by which to handle extreme volume fractions**

No error (default) | Error | Warning

Means by which to handle unusual volume fractions. Select Warning to be notified when the volume fraction crosses a specified range. Select Error to stop simulation at such events.

**Minimum liquid volume fraction — Value below which to trigger warning or error**  
 0.05 (default) | positive scalar between 0 and 1

Lower bound of the valid range for the liquid volume fraction in the tank. Fractions below this value will trigger a simulation warning or error (depending on the setting of the **Liquid volume fraction out of range** block parameter.

#### Dependencies

This parameter is active when the **Liquid volume fraction out of range** block parameter is set to Warning or Error.

**Maximum liquid volume fraction — Value above which to trigger warning or error**  
 0.95 (default) | positive scalar between 0 and 1

Upper bound of the valid range for the liquid volume fraction in the tank. Fractions above this value will trigger a simulation warning or error (depending on the setting of the **Liquid volume fraction out of range** block parameter.

#### Dependencies

This parameter is active when the **Liquid volume fraction out of range** block parameter is set to Warning or Error.

**Volume fraction threshold for transition to pure liquid or pure vapor — Volume fraction of a phase below which to transition to a single-phase tank**  
 20 W/(m<sup>2</sup>\*K) (default) | positive scalar with units of power/(area\*temperature)

Volume fraction of either phase below which to transition to a single-phase tank—either subcooled liquid or superheated vapor. This parameter determines how smooth the transition is. The larger its value, the smoother the transition and therefore the faster the simulation (though at the cost of lower accuracy).

## Heat Transfer

### **Vapor heat transfer coefficient — Coefficient for heat exchange between vapor and the tank wall**

20 W/(m<sup>2</sup>\*K) (default) | positive scalar with units of power/(area\*temperature)

Coefficient for heat exchange between the vapor zone and its section of the tank wall. This parameter serves to calculate the rate of this heat exchange.

### **Liquid heat transfer coefficient — Coefficient for heat exchange between liquid and the tank wall**

100 W/(m<sup>2</sup>\*K) (default) | positive scalar with units of power/(area\*temperature)

Coefficient for heat exchange between the liquid zone and its section of the tank wall. This parameter serves to calculate the rate of this heat exchange.

## Effects and Initial Conditions

### **Initial fluid energy specification — Thermodynamic variable whose initial value to set**

Liquid volume fraction (default) | Temperature | Liquid mass fraction | Specific enthalpy | Specific internal energy

Thermodynamic variable in terms of which to define the initial conditions of the component.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- **Temperature** — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- **Liquid mass fraction**— Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Liquid volume fraction**— Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid volume fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

### **Initial pressure — Absolute pressure at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure in the tank at the start of simulation, specified against absolute zero.

### **Initial temperature — Absolute temperature at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature in the tank at the start of simulation, specified against absolute zero.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Temperature.

**Initial liquid mass fraction — Mass fraction of liquid at the start of simulation**

0.5 (default) | unitless scalar between 0 and 1

Mass fraction of liquid in the tank at the start of simulation.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Liquid mass fraction.

**Initial liquid volume fraction — Volume fraction of liquid at the start of simulation**

0.5 (default) | unitless scalar between 0 and 1

Volume fraction of liquid in the tank at the start of simulation.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Liquid volume fraction.

**Initial specific enthalpy — Specific enthalpy at the start of simulation**

1500 kJ/kg (default) | scalar with units of energy/mass

Specific enthalpy of the fluid in the tank at the start of simulation.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Specific enthalpy.

**Initial specific internal energy — Specific internal energy at the start of simulation**

1500 kJ/kg (default) | scalar with units of energy/mass

Specific internal energy of the fluid in the tank at the start of simulation.

**Dependencies**

This parameter is active when the **Initial fluid energy specification** option is set to Specific internal energy.

**Vaporization and condensation time constant — Characteristic duration of a phase-change event**

0.1 s (default) | scalar with units of time

Characteristic time to equilibrium of a phase-change event taking place in the tank. Increase this parameter to slow the rate of phase change or decrease it to speed up the rate.

**Version History**

**Introduced in R2018b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

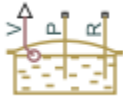
### **See Also**

3-Zone Pipe (2P) | Constant Volume Chamber (2P)



# Reservoir

Pressurized hydraulic reservoir



## Library

Hydraulic Utilities

### Description

The Reservoir block represents a pressurized hydraulic reservoir, in which fluid is stored under a specified pressure. The pressure remains constant regardless of volume change. The block accounts for pressure loss in the return line that can be caused by a filter, fittings, or some other local resistance. The loss is specified with the pressure loss coefficient. The block computes the volume of fluid in the tank and exports it outside through the physical signal port V.

The fluid volume value does not affect the results of simulation. It is introduced merely for information purposes. It is possible for the fluid volume to become negative during simulation, which signals that the fluid volume is not enough for the proper operation of the system. By viewing the results of the simulation, you can determine the extent of the fluid shortage.

### Parameters

#### Pressurization level

The pressure inside the reservoir. The default value is 0.

#### Initial fluid volume

The initial volume of fluid in the tank. The default value is 0.02 m<sup>3</sup>.

#### Return line diameter

The diameter of the return line. The default value is 0.02 m.

#### Pressure loss coefficient in return line

The value of the pressure loss coefficient, to account for pressure loss in the return line. This parameter must be greater than zero. The default value is 1.

For reasons of computational robustness, the loss is computed with the equation similar to that used in the Fixed Orifice block:

$$q = \frac{1}{\sqrt{K}} A_p \sqrt{\frac{2}{\rho} p_{loss}}$$

The Critical Reynolds number is set to 15.

## Ports

The block has the following ports:

P

Hydraulic conserving port associated with the pump line.

R

Hydraulic conserving port associated with the return line.

V

Physical signal port that outputs the volume of fluid in the tank.

## Version History

Introduced in R2006b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Constant Head Tank | Hydraulic Reference | Tank

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Resistive Pipe LP

Hydraulic pipeline which accounts for friction losses and port elevations



## Library

Low-Pressure Blocks

## Description

The Resistive Pipe LP block models hydraulic pipelines with circular and noncircular cross sections and accounts for resistive property only. In other words, the block is developed with the basic assumption of the steady state fluid momentum conditions. Neither fluid compressibility nor fluid inertia is considered in the model, meaning that features such as water hammer cannot be investigated. If necessary, you can add fluid compressibility, fluid inertia, and other effects to your model using other blocks, thus producing a more comprehensive model.

The end effects are also not considered, assuming that the flow is fully developed along the entire pipe length. To account for local resistances, such as bends, fittings, inlet and outlet losses, and so on, convert the resistances into their equivalent lengths, and then sum up all the resistances to obtain their aggregate length. Then add this length to the pipe geometrical length.

Pressure loss due to friction is computed with the Darcy equation, in which losses are proportional to the flow regime-dependable friction factor and the square of the flow rate. The friction factor in turbulent regime is determined with the Haaland approximation (see [1] on page 1-1584). The friction factor during transition from laminar to turbulent regimes is determined with the linear interpolation between extreme points of the regimes. As a result of these assumptions, the tube is simulated according to the following equations:

$$p = f \frac{(L + L_{eq})}{D_H} \frac{\rho}{2A^2} q \cdot |q| + \rho \cdot g(z_B - z_A)$$

$$f = \begin{cases} K_S/Re & \text{for } Re < = Re_L \\ f_L + \frac{f_T - f_L}{Re_T - Re_L}(Re - Re_L) & \text{for } Re_L < Re < Re_T \\ \frac{1}{\left(-1.8 \log_{10} \left( \frac{6.9}{Re} + \left( \frac{r/D_H}{3.7} \right)^{1.11} \right)\right)^2} & \text{for } Re > = Re_T \end{cases}$$

$$Re = \frac{q \cdot D_H}{A \cdot \nu}$$

where

$p$	Pressure loss along the pipe due to friction
$q$	Flow rate through the pipe
$Re$	Reynolds number
$Re_L$	Maximum Reynolds number at laminar flow
$Re_T$	Minimum Reynolds number at turbulent flow
$K_s$	Shape factor that characterizes the pipe cross section
$f_L$	Friction factor at laminar border
$f_T$	Friction factor at turbulent border
$A$	Pipe cross-sectional area
$D_H$	Pipe hydraulic diameter
$L$	Pipe geometrical length
$L_{eq}$	Aggregate equivalent length of local resistances
$r$	Height of the roughness on the pipe internal surface
$\nu$	Fluid kinematic viscosity
$z_A, z_B$	Elevations of the pipe port A and port B, respectively
$g$	Gravity acceleration

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Basic Assumptions and Limitations

- Flow is assumed to be fully developed along the pipe length.
- Fluid inertia, fluid compressibility, and wall compliance are not taken into account.

### Parameters

#### Basic Parameters Tab

##### Pipe cross section type

The type of pipe cross section: `Circular` or `Noncircular`. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is `Circular`.

**Internal diameter**

Pipe internal diameter. The parameter is used if **Pipe cross section type** is set to Circular. The default value is 0.01 m.

**Noncircular pipe cross-sectional area**

Pipe cross-sectional area. The parameter is used if **Pipe cross section type** is set to Noncircular. The default value is  $1e-4 \text{ m}^2$ .

**Noncircular pipe hydraulic diameter**

Hydraulic diameter of the pipe cross section. The parameter is used if **Pipe cross section type** is set to Noncircular. The default value is 0.0112 m.

**Geometrical shape factor**

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on [1 on page 1-1584]. The default value is 64, which corresponds to a pipe with a circular cross section.

**Pipe length**

Pipe geometrical length. The default value is 5 m.

**Aggregate equivalent length of local resistances**

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. The default value is 1 m.

**Internal surface roughness height**

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is  $1.5e-5 \text{ m}$ , which corresponds to drawn tubing.

**Laminar flow upper margin**

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

**Turbulent flow lower margin**

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

**Vertical Position Tab****Port A elevation wrt reference plane**

The parameter specifies vertical position of the pipe port A with respect to the reference plane. The default value is 0.

**Port B elevation wrt reference plane**

The parameter specifies vertical position of the pipe port B with respect to the reference plane. The default value is 0.

**Gravitational acceleration**

Value of the gravitational acceleration constant ( $g$ ). The block uses this parameter to compute the effects of an elevation gradient between the ports on their pressure differential. The default value is  $9.80655 \text{ m/s}^2$ .

## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Pipe cross section type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Pipe cross section type** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2009a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Hydraulic Pipeline | Hydraulic Pipe LP | Hydraulic Pipe LP with Variable Elevation | Linear Hydraulic Resistance | Resistive Pipe LP with Variable Elevation | Hydraulic Resistive Tube | Segmented Pipeline | Segmented Pipe LP

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Resistive Pipe LP with Variable Elevation

Hydraulic pipeline which accounts for friction losses and variable port elevations



## Library

Low-Pressure Blocks

## Description

The Resistive Pipe LP with Variable Elevation block models hydraulic pipelines with circular and noncircular cross sections and accounts for resistive property only. Use this block for low-pressure system simulation in which the pipe ends change their positions with respect to the reference plane. The elevations are provided through respective physical signal inputs.

To reduce model complexity, you can use this block to simulate not only a pipe itself, but also a combination of pipes and local resistances such as bends, fittings, inlet and outlet losses, associated with the pipe. You must convert the resistances into their equivalent lengths, and then sum up all the resistances to obtain their aggregate length. Then add this length to the pipe geometrical length.

Pressure loss due to friction is computed with the Darcy equation, in which losses are proportional to the flow regime-dependable friction factor and the square of the flow rate. The friction factor in turbulent regime is determined with the Haaland approximation (see [1] on page 1-1588). The friction factor during transition from laminar to turbulent regimes is determined with the linear interpolation between extreme points of the regimes. As a result of these assumptions, the tube is simulated according to the following equations:

$$p = f \frac{(L + L_{eq})}{D_H} \frac{\rho}{2A^2} q \cdot |q| + \rho \cdot g(z_B - z_A)$$

$$f = \begin{cases} K_S/Re & \text{for } Re < = Re_L \\ f_L + \frac{f_T - f_L}{Re_T - Re_L} (Re - Re_L) & \text{for } Re_L < Re < Re_T \\ \frac{1}{\left( -1.8 \log_{10} \left( \frac{6.9}{Re} + \left( \frac{r/D_H}{3.7} \right)^{1.11} \right) \right)^2} & \text{for } Re > = Re_T \end{cases}$$

$$Re = \frac{q \cdot D_H}{A \cdot \nu}$$

where

$p$	Pressure loss along the pipe due to friction
$q$	Flow rate through the pipe
$Re$	Reynolds number
$Re_L$	Maximum Reynolds number at laminar flow
$Re_T$	Minimum Reynolds number at turbulent flow
$K_s$	Shape factor that characterizes the pipe cross section
$f_L$	Friction factor at laminar border
$f_T$	Friction factor at turbulent border
$A$	Pipe cross-sectional area
$D_H$	Pipe hydraulic diameter
$L$	Pipe geometrical length
$L_{eq}$	Aggregate equivalent length of local resistances
$r$	Height of the roughness on the pipe internal surface
$\nu$	Fluid kinematic viscosity
$z_A, z_B$	Elevations of the pipe port A and port B, respectively
$g$	Gravity acceleration

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Basic Assumptions and Limitations

- Flow is assumed to be fully developed along the pipe length.
- Fluid inertia, fluid compressibility, and wall compliance are not taken into account.

### Ports

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.



eI\_A

Physical signal input port that controls pipe elevation at port A.

eI\_B

Physical signal input port that controls pipe elevation at port B.

## Parameters

### Basic Parameters

#### Pipe cross section type

The type of pipe cross section: **Circular** or **Noncircular**. For a circular pipe, you specify its internal diameter. For a noncircular pipe, you specify its hydraulic diameter and pipe cross-sectional area. The default value of the parameter is **Circular**.

#### Internal diameter

Pipe internal diameter. The parameter is used if **Pipe cross section type** is set to **Circular**. The default value is 0.01 m.

#### Noncircular pipe cross-sectional area

Pipe cross-sectional area. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is  $1e-4 \text{ m}^2$ .

#### Noncircular pipe hydraulic diameter

Hydraulic diameter of the pipe cross section. The parameter is used if **Pipe cross section type** is set to **Noncircular**. The default value is 0.0112 m.

#### Geometrical shape factor

Used for computing friction factor at laminar flow. The shape of the pipe cross section determines the value. For a pipe with a noncircular cross section, set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on [1 on page 1-1588]. The default value is 64, which corresponds to a pipe with a circular cross section.

#### Pipe length

Pipe geometrical length. The default value is 5 m.

#### Aggregate equivalent length of local resistances

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. The default value is 1 m.

#### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is  $1.5e-5 \text{ m}$ , which corresponds to drawn tubing.

#### Laminar flow upper margin

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

#### Turbulent flow lower margin

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

**Gravitational acceleration**

Value of the gravitational acceleration constant ( $g$ ). The block uses this parameter to calculate time changes in pressure due to time changes in elevation. The default value is  $9.80655 \text{ m/s}^2$ .

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**References**

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

**Version History**

Introduced in R2010a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Hydraulic Pipeline | Hydraulic Pipe LP | Hydraulic Pipe LP with Variable Elevation | Linear Hydraulic Resistance | Resistive Pipe LP | Hydraulic Resistive Tube | Segmented Pipeline | Segmented Pipe LP

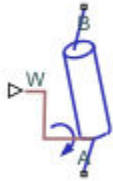
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Rotating Channel (IL)

Rotating pipe with a fluid channel in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings



### Description

The Rotating Channel (IL) block models a rotating pipe with a fluid channel in an isothermal liquid network. The pipe angular velocity is set by a physical signal at port **W**. Ports **A** and **B** are isothermal liquid inlet and outlet ports.

Fluid passing through a rotating channel experiences pressure changes due to resistance passing through the casing orifice and due to the fluid angular momentum. An internal connection to an Orifice (IL) block accounts for the local resistances. The pressure change in the block is modeled as:

$$P = \rho_A W^2 \frac{r_B^2}{2},$$

where:

- $\rho_A$  is the fluid density at port **A**.
- $W$  is the shaft angular velocity, received as a physical signal at port **W**.
- $r_B$  is the radius of rotation at port **B**.

The isothermal liquid outlet port can be connected to a Rotating Cylinder Force (IL) block to model components such as a Rotating Single-Acting Actuator (IL).

### Assumptions and Limitations

- The effects of fluid inertia are not calculated.
- The pipe angular velocity is assumed to be constant or changes very slowly.

### Ports

#### Conserving

#### **A — Liquid port**

isothermal liquid

Liquid entry or exit port.

#### **B — Liquid port**

isothermal liquid

Liquid entry or exit port.

### **Input**

#### **W — Angular velocity, rad/s**

physical signal

Rotating shaft angular velocity in rad/s, specified as a physical signal.

### **Parameters**

#### **Channel area — Shaft channel cross-sectional area**

1e-3 m<sup>2</sup> (default) | positive scalar

Shaft channel cross-sectional area for liquid entry/exit.

#### **Port B radius of rotation — Rotation radius**

0.01 m (default) | positive scalar

Radius of swept circle of pipe rotation, specified at port **B**.

#### **Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

#### **Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

## **Version History**

**Introduced in R2020a**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Rotating Cylinder Force (IL) | Orifice (IL) | Rotating Single-Acting Actuator (IL) | Single-Acting Rotary Actuator (IL) | Valve Plate Orifice (IL)

# Rotating Cylinder Force (IL)

Centripetal pressure gradient for components in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators / Auxiliary Components



## Description

The Rotating Cylinder Force (IL) block models the axial force due to a centripetal pressure gradient in a rotating shaft about its symmetry axis, which is found in applications such as friction clutches, square-jaw positive clutches, dog clutches, and brakes. Connect this block in parallel to a Single-Acting Actuator (IL) or a Translational Mechanical Converter (IL) block to model a rotating actuator. The fluid density is recorded at the isothermal liquid port **X**. The angular velocity is received as a physical signal at port **W**. Port **R** is associated with the piston velocity, relative to the case at port **C**.

The angular velocity of the shaft is assumed to be constant or nearly-constant, and therefore the fluid is considered to be in rigid-body rotation.

The centripetal force is due solely to the fluid angular momentum induced by shaft rotation. Removing the contribution of the static pressure in the fluid channel, the contribution of the rotation of the shaft to the axial force is:

$$F_{rotational} = \frac{\rho\pi W^2}{4}(r_o^4 - r_i^4 - 2r_p^2(r_o^2 - r_i^2)),$$

where:

- $\rho$  is the fluid density at port **X**.
- $W$  is the angular velocity of the rotating pipe, received as a physical signal at port **W**.
- $r_o$  is the **Piston outer radius**.
- $r_i$  is the **Piston inner radius**.
- $r_p$  is the **Fluid entry radius**.

## Ports

### Conserving

#### **X** – Liquid density port

isothermal liquid

Liquid port associated with fluid density. There is no mass flow through port **X**. Connect port **X** to port **A** of the Single-Acting Actuator (IL) or Translational Mechanical Converter (IL) blocks.

#### **C** – Cylinder casing

mechanical translational

Mechanical translational conserving port associated with the cylinder casing reference velocity and force.

**R – Piston**

mechanical translational

Mechanical translational conserving port associated with the piston velocity and force induced by the pressure differential.

**Input****W – Angular velocity, rad/s**

physical signal

Angular velocity in rad/s, specified as a physical signal.

**Parameters****Piston outer radius – Piston outer radius**

0.1 m (default) | positive scalar

Piston outer radius.

**Piston inner radius – Piston inner radius**

0.05 m (default) | positive scalar

Piston inner radius.

**Fluid entry radius – Fluid channel radius**

0.06 m (default) | positive scalar

Radius of the fluid opening in the cylinder casing, measured from the rotational axis. This value must be greater than or equal to the **Piston inner radius** and less than or equal to the **Piston outer radius**.

**Actuator mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Piston displacement direction of the connected actuator block. Pressure at A causes positive displacement of R relative to C corresponds to positive displacement, or actuator shaft extension, when **R - C** is positive. Pressure at A causes negative displacement of R relative to C corresponds to negative displacement, or actuator shaft retraction, when **R - C** is positive.

**Version History**

Introduced in R2020a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Rotating Channel (IL) | Single-Acting Actuator (IL) | Translational Mechanical Converter (IL) | Single-Acting Rotary Actuator (IL)

## Rotating Pipe

Hydraulic pipeline created by bore in rotating housing

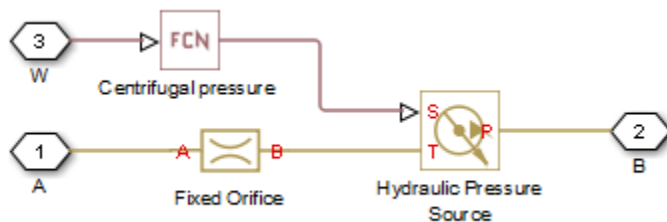


## Library

Pipelines

### Description

The Rotating Pipe block models a hydraulic pipeline represented as a short bore drilled through a shaft at some angle to its axis, or as a short pipe that connects actuator or bearings, mounted on the shaft, with the channel inside the shaft. Such connections are typical for lubrication systems and for hydraulically-operated clutches and mechanisms. The shaft angular velocity is assumed to be constant or changing at very low speed. The block is implemented as a structural model, shown in the diagram below:



The Fixed Orifice block simulates pressure losses in the bore. The pipe is assumed to be short enough to be characterized by a flow-pressure relationship similar to that of the fixed orifice. The model accounts for the laminar and turbulent flow regimes by monitoring the Reynolds number ( $Re$ ) and comparing its value with the critical Reynolds number ( $Re_{cr}$ ). The Hydraulic Pressure Source block represents pumping action developed by a rotating pipe, which is calculated with the equation:

$$p = \rho \cdot \frac{\omega^2 \cdot r_B^2}{2}$$

where

$p$	Pressure at the pipe outlet
$\rho$	Fluid density
$\omega$	Shaft angular velocity



$r_B$	Radius of the pipe outlet
-------	---------------------------

Connections A and B are conserving hydraulic ports associated with the pipe inlet and outlet, respectively. Connection W is the physical signal input port that provides the shaft angular velocity value.

## Basic Assumptions and Limitations

- The pipe is assumed to be short, to be simulated with the fixed orifice.
- Flow is assumed to be fully developed along the pipe length.
- The transition between laminar and turbulent regimes is assumed to be sharp and taking place exactly at  $Re=Re_{cr}$ .
- Fluid inertia is not taken into account.
- Fluid compressibility is not taken into account.

## Parameters

### Pipe cross-section area

Cross-sectional area of the pipe. The default value is  $1e-4 \text{ m}^2$ .

### Port B radius of rotation

Radius of rotation of the outer end of the pipe. The default value is  $0.03 \text{ m}$ .

### Flow discharge coefficient

Semi-empirical parameter for pipe capacity characterization. Its value depends on the geometrical properties of the pipe, and usually is provided in textbooks or manufacturer data sheets. The default value is  $0.6$ .

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches this value. The value of the parameter depends on the pipe geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is  $12$ , which corresponds to a round orifice in thin material with sharp edges.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Examples

For an example on page 1-447 of using the Rotating Pipe block to model a custom single-acting hydraulic cylinder, see the Centrifugal Force in Rotating Cylinder block reference page.

## **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

W

Physical signal port providing the angular velocity value.

## **Version History**

**Introduced in R2010a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Centrifugal Force in Rotating Cylinder

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Rotating Single-Acting Actuator (IL)

Actuator on a rotating shaft in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators



## Description

The Rotating Single-Acting Actuator (IL) block models an actuator that rotates around its central axis in an isothermal liquid network. Rotating actuators are used in rotating shaft control components such as friction clutches or brakes. The fluid enters the actuator at port **A**. The angular velocity is set at port **W**. Port **C** is associated with the actuator casing and the piston velocity and force are set at port **R**.

When the piston position is calculated internally, it is reported at port **p**, and when the position is set by a connection to a Simscape Multibody joint, it is received as a physical signal at port **p**. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models. **Fluid dynamic compressibility** can optionally be modeled.

## Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\Theta$ , when the chamber volume is equal to the **Dead volume**. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

## Hard Stop Model

To avoid mechanical damage to an actuator when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Double-Acting Actuator (IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.
- Full stiffness and damping applied at bounds, damped rebound.

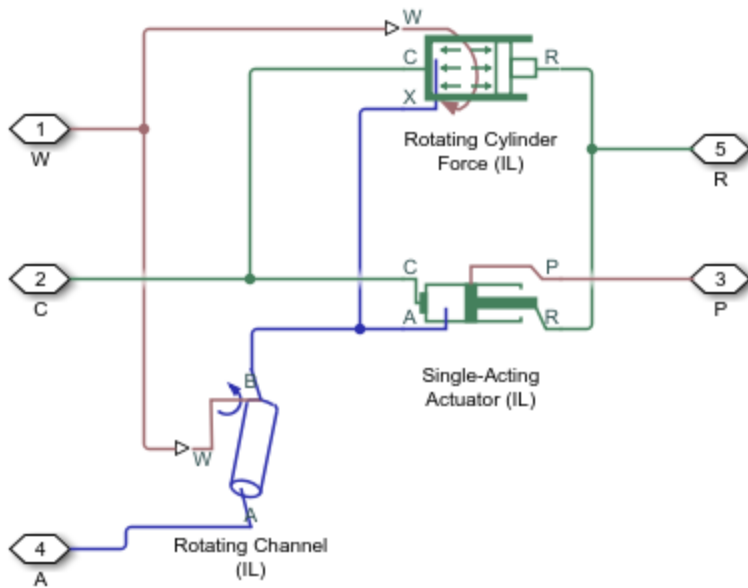
The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Piston stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

For more information about these settings, see the Translational Hard Stop block page.

## Block Subcomponents

The Rotating Single-Acting Actuator (IL) block comprises three Isothermal Liquid library blocks:

- Rotating Channel (IL)
- Single-Acting Actuator (IL)
- Rotating Cylinder Force (IL)



### Actuator Schematic

### Ports

#### Conserving

#### A – Liquid chamber inlet port

isothermal liquid

Inlet port to the liquid chamber.

#### C – Actuator casing

mechanical translational

Reference port for actuator velocity and force.

#### R – Rod velocity

mechanical translational

Port associated with the piston velocity and force.

#### Input

#### W – Actuator rotational velocity

physical signal

Actuator rotational velocity, received as a physical signal in rad/s.

**p — Piston position, m**

physical signal

Piston position in m, received as a physical signal from a Simscape Multibody block.

**Dependencies**

To expose this port, set **Piston displacement** to Provide input signal from Multibody joint.

**Output****p — Piston position, m**

physical signal

Piston position in m, returned as a physical signal.

**Dependencies**

To expose this port, set **Piston displacement** to Calculate from velocity of port R relative to port C.

**Parameters****Actuator****Piston outer radius — Piston outer radius**

0.1 m (default) | positive scalar

Piston outer radius.

**Piston inner radius — Piston inner radius**

0.05 m (default) | positive scalar

Piston inner radius.

**Mechanical orientation — Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

**Piston stroke — Maximum piston travel distance**

0.1 m (default) | positive scalar

Maximum piston travel distance.

**Dead volume — Fluid volume at full piston retraction**1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0. This is the liquid volume when the piston is up against the actuator end cap.

**Environment pressure specification — Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

**Environment pressure — User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Fluid Channel****Fluid entry radius — Fluid channel radius**

0.06 m (default) | positive scalar

Radius of the fluid opening in the rotating shaft. This value must be greater than or equal to the **Piston inner radius** and less than or equal to the **Piston outer radius**.

**Fluid channel cross-sectional area — Fluid cross-sectional area**

1e-3 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the fluid channel.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Flow discharge loss coefficient.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Hard Stop****Hard-stop stiffness coefficient — Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient. This value must be greater than 0.

**Hard-stop damping coefficient — Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient.

**Hard stop model — Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

### Transition region — Application range of hard stop force model

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of the range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

#### Dependencies

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

#### Initial Conditions

### Piston displacement — Method for determining piston position

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the piston position. The block can receive the position from a Multibody block when set to Provide input signal from Multibody joint, or calculates the position internally and reports the position at port **p**. The position is between 0 and the **Piston stroke** when the mechanical orientation is positive and 0 and **-Piston stroke** when the mechanical orientation is negative.

### Initial piston displacement — Piston position at start of simulation

0 m (default) | scalar

Piston position at the start of the simulation.

#### Dependencies

To enable this parameter, set **Piston displacement** to Calculate from velocity of port R relative to port C.

### Fluid dynamic compressibility — Whether to model fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

### Initial liquid pressure — Starting liquid pressure for compressible fluids

0.101325 MPa (default) | positive scalar

Starting liquid pressure for compressible fluids.

#### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

## **Version History**

**Introduced in R2020a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Single-Acting Actuator (IL) | Single-Acting Rotary Actuator (IL) | Pilot Valve Actuator (IL) | Double-Acting Actuator (IL) | Double-Acting Actuator (G-IL)

## **Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”



# Segmented Pipeline

Hydraulic pipeline with resistive, fluid inertia, and fluid compressibility properties

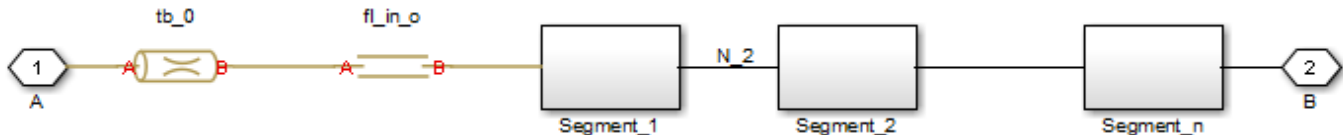


## Library

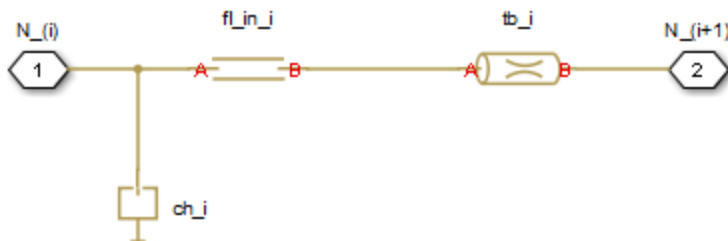
Pipelines

## Description

The Segmented Pipeline block models hydraulic pipelines with circular cross sections. Hydraulic pipelines, which are inherently distributed parameter elements, are represented with sets of identical, connected in series, lumped parameter segments. It is assumed that the larger the number of segments, the closer the lumped parameter model becomes to its distributed parameter counterpart. The equivalent circuit of a pipeline adopted in the block is shown below, along with the segment configuration.



## Pipeline Equivalent Circuit



## Segment Configuration

The model contains as many Constant Volume Hydraulic Chamber blocks as there are segments. The chamber lumps fluid volume equal to

$$V = \frac{\pi \cdot d^2 L}{4 N}$$

where

$V$	Fluid volume
$d$	Pipe diameter
$L$	Pipe length
$N$	Number of segments

The Constant Volume Hydraulic Chamber block is placed between two branches, each consisting of a Hydraulic Resistive Tube block and a Fluid Inertia block. Every Hydraulic Resistive Tube block lumps  $(L+L_{ad})/(N+1)$ -th portion of the pipe length, while Fluid Inertia block has  $L/(N+1)$  length ( $L_{ad}$  denotes additional pipe length equal to aggregate equivalent length of pipe local resistances, such as fitting, elbows, bends, and so on).

The nodes to which Constant Volume Hydraulic Chamber blocks are connected are assigned names  $N_1, N_2, \dots, N_n$  ( $n$  is the number of segments). Pressures at these nodes are assumed to be equal to average pressure of the segment. Intermediate nodes between Hydraulic Resistive Tube and Fluid Inertia blocks are assigned names  $nn_0, nn_1, nn_2, \dots, nn_n$ . The Constant Volume Hydraulic Chamber blocks are named  $ch_1, ch_2, \dots, ch_n$ , Hydraulic Resistive Tube blocks are named  $tb_0, tb_1, tb_2, \dots, tb_n$ , and Fluid Inertia blocks are named  $fl\_in_0, fl\_in_1, fl\_in_2, \dots, fl\_in_n$ .

The number of segments determines the number of computational nodes associated with the block. A higher number increases model fidelity but decreases simulation speed. Experiment with different numbers to obtain a suitable trade-off between accuracy and speed. Use the following equation as a starting point in estimating a suitable number of segments:

$$N > \frac{4L}{\pi \cdot c} \omega$$

where:

$N$	Number of segments
$L$	Pipe length
$c$	Speed of sound in the fluid
$\omega$	Maximum frequency to be observed in the pipe response

The table contains an example of simulation of a pipeline where the first four true eigenfrequencies are 89.1 Hz, 267 Hz, 446 Hz, and 624 Hz.

Number of Segments	1st Mode	2nd Mode	3rd Mode	4th Mode
1	112.3	-	-	-
2	107.2	271.8	-	-
4	97.7	284.4	432.9	689
8	93.2	271.9	435.5	628

The error between simulated and actual eigenfrequencies is less than 5% if an eight-segment model is used.

The flow rate through the pipeline is positive if it is directed from port A to port B. The pressure differential is positive if pressure is higher at port A than at port B.

## Basic Assumptions and Limitations

Flow is assumed to be fully developed along the pipe length.

## Parameters

### Pipe internal diameter

Internal diameter of the pipe. The default value is 0.01 m.

### Pipe length

Pipe geometrical length. The default value is 5 m.

### Number of segments

Number of lumped parameter segments in the pipeline model. The default value is 1.

### Aggregate equivalent length of local resistances

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. This length is added to the geometrical pipe length only for hydraulic resistance computation. Both the fluid volume and fluid inertia are determined based on pipe geometrical length only. The default value is 1 m.

### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is  $1.5e-5$  m, which corresponds to drawn tubing.

### Laminar flow upper margin

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

### Turbulent flow lower margin

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

### Pipe wall type

The parameter can have one of two values: `Rigid Wall` or `Flexible Wall`. If the parameter is set to `Rigid Wall`, wall compliance is not taken into account, which can improve computational efficiency. The value `Flexible Wall` is recommended for hoses and metal pipes where wall compliance can affect the system behavior. The default value is `Rigid Wall`.

### Static pressure-diameter coefficient

Coefficient that establishes relationship between the pressure and the internal diameter at steady-state conditions. This coefficient can be determined analytically for cylindrical metal pipes or experimentally for hoses. The parameter is used if the **Pipe wall type** parameter is set to `Flexible Wall`, and the default value is  $2e-10$  m/Pa.

### Viscoelastic process time constant

Time constant in the transfer function that relates pipe internal diameter to pressure variations. By using this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The value is determined experimentally or provided by the manufacturer. The default value is 0.008 s.

**Specific heat ratio**

Gas-specific heat ratio for the Constant Volume Hydraulic Chamber block. The default value is 1.4.

**Initial pressures at model nodes**

Lets you specify the initial condition for pressure inside the pipe segments. The parameter can have one of two values:

- **The same initial pressure for all nodes** — The initial pressure in all pipe segments is the same, and is specified by the **Initial pressure** parameter value. This is the default.
- **Custom** — Lets you specify initial pressure individually for each pipe segment, by using the **Initial pressure vector** parameter. The vector size must be equal to the number of pipe segments, defined by the **Number of segments** parameter value.

**Initial pressure**

Specifies the initial pressure in all pipe segments. The parameter is used if the **Initial pressures at model nodes** parameter is set to **The same initial pressure for all nodes**, and the default value is 0.

**Initial pressure vector**

Lets you specify initial pressure individually for each pipe segment. The parameter is used if the **Initial pressures at model nodes** parameter is set to **Custom**. The vector size must be equal to the number of pipe segments, defined by the **Number of segments** parameter value.

**Initial flow rate**

Specifies the initial volumetric flow rate through the pipe. The default value is 0 m<sup>3</sup>/s.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Pipe wall type**
- **Initial pressures at model nodes**

All other block parameters are available for modification.

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

## **Version History**

**Introduced in R2006a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Hydraulic Pipeline | Linear Hydraulic Resistance | Hydraulic Resistive Tube

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Segmented Pipe LP

Hydraulic pipeline with resistive, fluid inertia, fluid compressibility, and elevation properties

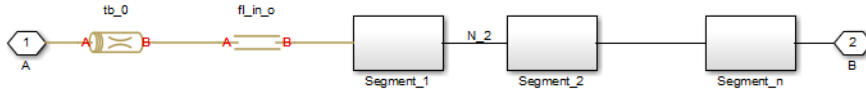


## Library

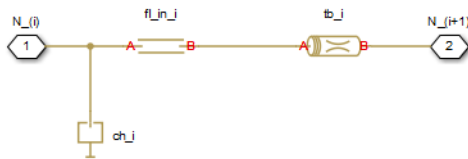
Low-Pressure Blocks

## Description

The Segmented Pipe LP block models hydraulic pipelines with circular cross sections. Hydraulic pipelines, which are inherently distributed parameter elements, are represented with sets of identical, connected in series, lumped parameter segments. It is assumed that the larger the number of segments, the closer the lumped parameter model becomes to its distributed parameter counterpart. The equivalent circuit of a pipeline adopted in the block is shown below, along with the segment configuration.



## Pipeline Equivalent Circuit



## Segment Configuration

The model contains as many Constant Volume Hydraulic Chamber blocks as there are segments. The chamber lumps fluid volume equal to

$$V = \frac{\pi \cdot d^2 L}{4 N}$$

where

$V$	Fluid volume
$d$	Pipe diameter
$L$	Pipe length

$N$	Number of segments
-----	--------------------

The Constant Volume Hydraulic Chamber block is placed between two branches, each consisting of a Resistive Pipe LP block and a Fluid Inertia block. Every Resistive Pipe LP block lumps  $(L+L_{ad})/(N+1)$ -th portion of the pipe length, while Fluid Inertia block has  $L/(N+1)$  length ( $L_{ad}$  denotes additional pipe length equal to aggregate equivalent length of pipe local resistances, such as fitting, elbows, bends, and so on).

The nodes to which Constant Volume Hydraulic Chamber blocks are connected are assigned names  $N_1, N_2, \dots, N_n$  ( $n$  is the number of segments). Pressures at these nodes are assumed to be equal to average pressure of the segment. Intermediate nodes between Resistive Pipe LP and Fluid Inertia blocks are assigned names  $nn_0, nn_1, nn_2, \dots, nn_n$ . The Constant Volume Hydraulic Chamber blocks are named  $ch_1, ch_2, \dots, ch_n$ , Resistive Pipe LP blocks are named  $tb_0, tb_1, tb_2, \dots, tb_n$ , and Fluid Inertia blocks are named  $fl\_in_0, fl\_in_1, fl\_in_2, \dots, fl\_in_n$ .

The number of segments determines the number of computational nodes associated with the block. A higher number increases model fidelity but decreases simulation speed. Experiment with different numbers to obtain a suitable trade-off between accuracy and speed. Use the following equation as a starting point in estimating a suitable number of segments:

$$N > \frac{4L}{\pi \cdot c} \omega$$

where

$N$	Number of segments
$L$	Pipe length
$c$	Speed of sound in the fluid
$\omega$	Maximum frequency to be observed in the pipe response

The table below contains an example of simulation of a pipeline where the first four true eigenfrequencies are 89.1 Hz, 267 Hz, 446 Hz, and 624 Hz.

Number of Segments	1st Mode	2nd Mode	3rd Mode	4th Mode
1	112.3	-	-	-
2	107.2	271.8	-	-
4	97.7	284.4	432.9	689
8	93.2	271.9	435.5	628

As you can see, the error is less than 5% if an eight-segmented version is used.

The difference in elevation between ports A and B is distributed evenly between pipe segments.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as  $\Delta p = p_A - p_B$ .

## Basic Assumptions and Limitations

Flow is assumed to be fully developed along the pipe length.

## Parameters

- “Basic Parameters Tab” on page 1-1610
- “Wall Compliance Tab” on page 1-1610
- “Vertical Position Tab” on page 1-1611

### Basic Parameters Tab

#### Pipe internal diameter

Internal diameter of the pipe. The default value is 0.01 m.

#### Pipe length

Pipe geometrical length. The default value is 5 m.

#### Number of segments

Number of lumped parameter segments in the pipeline model. The default value is 1.

#### Aggregate equivalent length of local resistances

This parameter represents total equivalent length of all local resistances associated with the pipe. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. This length is added to the geometrical pipe length only for hydraulic resistance computation. Both the fluid volume and fluid inertia are determined based on pipe geometrical length only. The default value is 1 m.

#### Internal surface roughness height

Roughness height on the pipe internal surface. The parameter is typically provided in data sheets or manufacturer’s catalogs. The default value is  $1.5e-5$  m, which corresponds to drawn tubing.

#### Laminar flow upper margin

Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

#### Turbulent flow lower margin

Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

#### Initial liquid pressure

Gauge pressure in the pipe segments at time zero. Enter a scalar for a single-segment pipeline and a vector for a multi-segment pipeline. The number of elements in the vector must match the number of segments in the pipe. The default value is 0 Pa.

### Wall Compliance Tab

#### Pipe wall type

The parameter can have one of two values: `Rigid Wall` or `Flexible Wall`. If the parameter is set to `Rigid Wall`, wall compliance is not taken into account, which can improve computational efficiency. The value `Flexible Wall` is recommended for hoses and metal pipes where wall compliance can affect the system behavior. The default value is `Rigid Wall`.

#### Static pressure-diameter coefficient

Coefficient that establishes relationship between the pressure and the internal diameter at steady-state conditions. This coefficient can be determined analytically for cylindrical metal pipes



or experimentally for hoses. The parameter is used if the **Pipe wall type** parameter is set to **Flexible**. The default value is  $2e-12$  m/Pa.

#### **Viscoelastic process time constant**

Time constant in the transfer function that relates pipe internal diameter to pressure variations. By using this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The value is determined experimentally or provided by the manufacturer. The parameter is used if the **Pipe wall type** parameter is set to **Flexible Wall**. The default value is 0.01 s.

#### **Specific heat ratio**

Gas-specific heat ratio for the Constant Volume Hydraulic Chamber block. The default value is 1.4.

#### **Vertical Position Tab**

##### **Port A elevation wrt reference plane**

Vertical position of port **A** with respect to a reference plane. The reference plane is assumed to be the same as that used in the **Port B elevation from reference plane** parameter. The default value is 0m.

##### **Port B elevation wrt reference plane**

Vertical position of port **B** with respect to a reference plane. The reference plane is assumed to be the same as that used in the **Port A elevation from reference plane** parameter. The default value is 0m.

#### **Gravitational acceleration**

Value of the gravitational acceleration constant ( $g$ ). The block uses this parameter to compute the effects of an elevation gradient between the ports on their pressure differential. The default value is  $9.80665$  m/s<sup>2</sup>.

## **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Pipe wall type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Pipe wall type** parameter at the time the model entered Restricted mode.

## **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the pipe inlet.

B

Hydraulic conserving port associated with the pipe outlet.

## References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

## Version History

Introduced in R2009a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Hydraulic Pipeline | Hydraulic Pipe LP | Linear Hydraulic Resistance | Resistive Pipe LP | Hydraulic Resistive Tube | Segmented Pipeline

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Shuttle Valve

Hydraulic valve that allows flow in one direction only



## Library

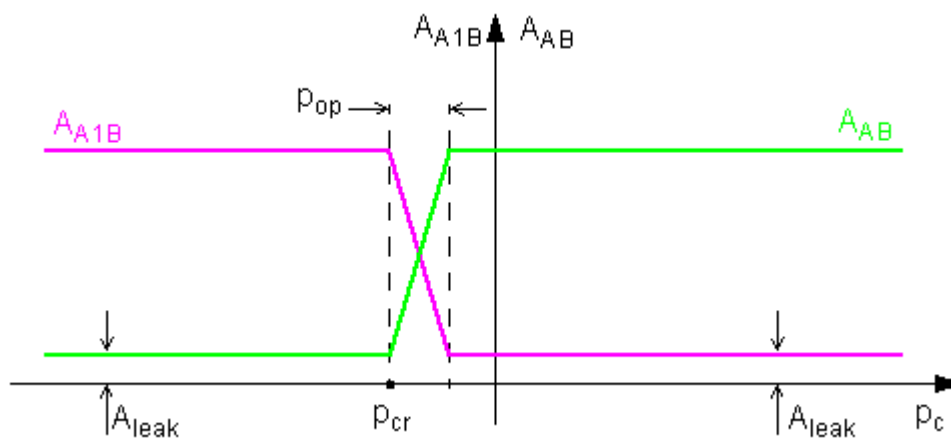
Directional Valves

### Description

The Shuttle Valve block represents a hydraulic shuttle valve as a data-sheet-based model. The valve has two inlet ports (A and A1) and one outlet port (B). The valve is controlled by pressure differential  $p_c = p_A - p_{A1}$ . The valve permits flow either between ports A and B or between ports A1 and B, depending on the pressure differential  $p_c$ . Initially, path A-B is assumed to be opened. To open path A1-B (and close A-B at the same time), pressure differential must be less than the valve cracking pressure ( $p_{cr} \leq 0$ ).

When cracking pressure is reached, the valve control member (spool, ball, poppet, etc.) is forced off its seat and moves to the opposite seat, thus opening one passage and closing the other. If the flow rate is high enough and pressure continues to change, the control member continues to move until it reaches its extreme position. At this moment, one of the valve passage areas is at its maximum. The valve maximum area and the cracking and maximum pressures are generally provided in the catalogs and are the three key parameters of the block.

The relationship between the A-B, A1-B path openings and control pressure  $p_c$  is shown in the following illustration.



In addition to the maximum area, the leakage area is also required to characterize the valve. The main purpose of the parameter is not to account for possible leakage, even though this is also

important, but to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause failure of computation. Therefore, the parameter value must be greater than zero.

The flow rate through each of the orifices is determined according to the following equations:

$$q_{AB} = C_D \cdot A_{AB} \sqrt{\frac{2}{\rho}} \cdot \frac{p_{AB}}{(p_{AB}^2 + p_{cr}^2)^{1/4}}$$

$$q_{A1B} = C_D \cdot A_{A1B} \sqrt{\frac{2}{\rho}} \cdot \frac{p_{A1B}}{(p_{A1B}^2 + p_{cr}^2)^{1/4}}$$

$$A_{AB} = \begin{cases} A_{leak} & \text{for } p_c \leq p_{crack} \\ A_{leak} + k \cdot (p_c - p_{crack}) & \text{for } p_{crack} < p_c < p_{crack} + p_{op} \\ A_{max} & \text{for } p_c \geq p_{crack} + p_{op} \end{cases}$$

$$A_{A1B} = \begin{cases} A_{leak} & \text{for } p_c \geq p_{crack} + p_{op} \\ A_{max} - k \cdot (p_c - p_{crack}) & \text{for } p_{crack} < p_c < p_{crack} + p_{op} \\ A_{max} & \text{for } p_c \leq p_{crack} \end{cases}$$

$$k = \frac{A_{max} - A_{leak}}{p_{op}}$$

$$p_c = p_A - p_{A1}$$

where

$q_{AB}, q_{A1B}$	Flow rates through the AB and A1B orifices
$p_{AB}, p_{A1B}$	Pressure differentials across the AB and A1B orifices
$p_A, p_{A1}, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$\rho$	Fluid density
$A_{AB}, A_{A1B}$	Instantaneous orifice AB and A1B passage areas
$A_{max}$	Fully open orifice passage area
$A_{leak}$	Closed valve leakage area
$p_c$	Valve control pressure differential
$p_{crack}$	Valve cracking pressure differential
$p_{op}$	Pressure differential needed to fully shift the valve
$p_{crAB}, p_{crA1B}$	Minimum pressures for turbulent flow across the AB and A1B orifices

The minimum pressures for turbulent flow across the AB and A1B orifices,  $p_{crAB}$  and  $p_{crA1B}$ , are calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{crAB} = (p_{avgAB} + p_{atm})(1 - B_{lam})$$

$$p_{crA1B} = (p_{avgA1B} + p_{atm})(1 - B_{lam})$$

$$p_{avgAB} = (p_A + p_B)/2$$

$$p_{avgA1B} = (p_{A1} + p_B)/2$$

where

$p_{avgAB}$	Average pressure for orifice AB
$p_{avgA1B}$	Average pressure for orifice A1B
$p_{atm}$	Atmospheric pressure, 101325 Pa
$B_{lam}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{crAB} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_{HAB}} \right)^2$$

$$p_{crA1B} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_{HA1B}} \right)^2$$

$$D_{HAB} = \sqrt{\frac{4A_{AB}}{\pi}}$$

$$D_{HA1B} = \sqrt{\frac{4A_{A1B}}{\pi}}$$

where

$D_{HAB}, D_{HA1B}$	Instantaneous orifice hydraulic diameters
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

By default, the block does not include valve opening dynamics. Adding valve opening dynamics provides continuous behavior that is particularly helpful in situations with rapid valve opening and closing. The orifice passage areas  $A_{AB}$  and  $A_{A1B}$  in the equations above then become steady-state orifice AB and A1B passage areas, respectively. Instantaneous orifice AB and A1B passage areas with opening dynamics are determined as follows:

$$A_{AB\_dyn}(t = 0) = A_{AB\_init}$$

$$\frac{dA_{AB\_dyn}}{dt} = \frac{A_{AB} - A_{AB\_dyn}}{\tau}$$

$$A_{A1B\_dyn} = A_{max} + A_{leak} - A_{AB\_dyn}$$

where

$A_{AB\_dyn}$	Instantaneous orifice AB passage area with opening dynamics
$A_{A1B\_dyn}$	Instantaneous orifice A1B passage area with opening dynamics
$A_{AB\_init}$	Initial open area for orifice AB
$\tau$	Time constant for the first order response of the valve opening
$t$	Time

The block positive direction is from port A to port B and from port A1 to port B. Control pressure is determined as  $p_c = p_A - p_{A1}$ .

## Basic Assumptions and Limitations

- Valve opening is linearly proportional to the pressure differential.
- No loading on the valve, such as inertia, friction, spring, and so on, is considered.

## Parameters

### Maximum passage area

Valve passage maximum cross-sectional area. The default value is  $1e-4 \text{ m}^2$ .

### Cracking pressure

Pressure differential level at which the orifice of the valve starts to open. The default value is  $-1e4 \text{ Pa}$ .

### Opening pressure

Pressure differential across the valve needed to shift the valve from one extreme position to another. The default value is  $1e4 \text{ Pa}$ .

### Flow discharge coefficient

Semi-empirical parameter for valve capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is  $0.7$ .

### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is  $0.999$ . This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics

textbooks. The default value is 12, which corresponds to a round orifice in thin material with sharp edges. This parameter is visible only if the **Laminar transition specification** parameter is set to Reynolds number.

### Leakage area

The total area of possible leaks in the completely closed valve. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### Opening dynamics

Select one of the following options:

- **Do not include valve opening dynamics** — The valve sets its orifice passage area directly as a function of pressure. If the area changes instantaneously, so does the flow equation. This is the default.
- **Include valve opening dynamics** — Provide continuous behavior that is more physically realistic, by adding a first-order lag during valve opening and closing. Use this option in hydraulic simulations with the local solver for real-time simulation. This option is also helpful if you are interested in valve opening dynamics in variable step simulations.

### Opening time constant

The time constant for the first order response of the valve opening. This parameter is available only if **Opening dynamics** is set to **Include valve opening dynamics**. The default value is 0.1 s.

### Initial area at port A

The initial open area for orifice AB. This parameter is available only if **Opening dynamics** is set to **Include valve opening dynamics**. The default value is  $1e-4 \text{ m}^2$ .

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Opening dynamics**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Opening dynamics** parameter at the time the model entered Restricted mode.

### Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

### Ports

The block has the following ports:

A

Hydraulic conserving port associated with the valve inlet.

A1

Hydraulic conserving port associated with the valve inlet.

B

Hydraulic conserving port associated with the valve outlet.

## **Version History**

**Introduced in R2006b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Check Valve | Pilot-Operated Check Valve

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”



# Shuttle Valve (IL)

One-way switching valve in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Directional Control Valves



## Description

The Shuttle Valve (IL) block models a one-way pressure control valve or switching component in an isothermal liquid network. Flow through the valve travels from port **A** or port **A1** to port **B**. When the pressure differential between **A** and **A1**,  $p_{AA1}$ , is above a specified threshold pressure, the path between ports **A** and **B** is open to flow and the port at **A1** closes. The path has been fully changed when the pressure reaches the **Pressure at which A-B is fully open and A1-B is fully closed**. When  $p_{AA1}$  falls below the threshold pressure, the flow inlet switches to port **A1**.

### Mass Flow Rate Equation

Mass is conserved through the valve:

$$\dot{m}_A + \dot{m}_{A1} + \dot{m}_B = 0.$$

There is no flow between ports **A** and **A1**.

The mass flow rate through the valve is calculated as:

$$\dot{m} = \frac{C_d A_{valve} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left( 1 - \left( \frac{A_{valve}}{A_{port}} \right)^2 \right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{valve}$  is the valve open area, either between ports **A** and **B** or ports **A1** and **B**.
- $A_{port}$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the valve pressure difference. Depending on the flow path through the valve, this is either  $p_A - p_B$ ,  $p_{A1} - p_B$ , or the normalized pressure when switching between the two inlet ports,  $\hat{p}$ , defined below.

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , and is also dependent on the flow path through the valve:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{valve}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

The critical Reynolds number is the flow regime transition point between laminar and turbulent flow.

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area, and can change if different valve flow paths have different areas.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{valve}}{A_{port}}}{\sqrt{1 - \left(\frac{A_{valve}}{A_{port}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{valve}}{A_{port}}}$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set the **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

The opening area,  $A_{valve}$ , is also impacted by the valve opening dynamics.

### Opening Parameterization

The linear parameterization of the valve area depends on the flow path through the valve. The dynamic area is based on a normally open path between ports **A** and **B**:

$$A_{valve, AB} = \hat{p}(A_{max} - A_{leak}) + A_{leak}$$

The normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{AA1} - p_{open, A1B}}{p_{open, AB} - p_{open, A1B}}$$

when  $p_{AA1}$  is between the parameters **Pressure at which A-B is fully closed and A1-B is fully open** and **Pressure at which A-B is fully open and A1-B is fully closed**. If  $p_{AA1}$  is below **Pressure at which A-B is fully closed and A1-B is fully open**,  $\hat{p}$  is 0. If  $p_{AA1}$  is above **Pressure at which A-B is fully open and A1-B is fully closed**,  $\hat{p}$  is 1.

When the valve inlet switches from port **A** to port **A1**, the valve opening area is:

$$A_{valve, A1B} = A_{max} + A_{leak} - A_{valve, AB}$$

When the valve is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the normalized control pressure between 0 and 1. For more information, see “Numerical Smoothing”.

### Opening Dynamics

If opening dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{control}$  becomes the dynamic control pressure,  $p_{dyn}$ ; otherwise,  $p_{control}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Opening time constant**,  $\tau$ :

$$\dot{p}_{dyn, AB} = \frac{p_{control} - p_{dyn, AB}}{\tau}$$

By default, **Opening dynamics** is set to Off.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Entry port to the valve.

#### **A1 – Liquid port**

isothermal liquid

Entry port to the valve.

#### **B – Liquid port**

isothermal liquid

Exit port from the valve.

## Parameters

### **Pressure at which A-B is fully closed and A1-B is fully open – Threshold pressure for fully open inlet A1**

-0.01 MPa (default) | scalar

Pressure threshold between ports **A** and **A1**, below which the flow path between ports **A1** and **B** is fully open and the flow path between ports **A** and **B** is fully closed.

### **Pressure at which A-B is fully open and A1-B is fully closed – Threshold pressure for fully open inlet A**

0.01 MPa (default) | scalar

Pressure threshold between ports **A** and **A1**, above which the flow path between ports **A** and **B** is fully open and the flow path between ports **A1** and **B** is fully closed.

### **Maximum opening area – Maximum valve area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum open area of the valve. This value is used to determine the normalized valve pressure and the valve opening area during operation.

### **Leakage area – Gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

### **Cross-sectional area at ports A and B – Area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A**, **A1**, and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the valve.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

**Opening dynamics — Whether to introduce flow lag due to valve opening**

Off (default) | On

Whether to account for transient effects to the fluid system due to opening the valve. Setting **Opening dynamics** to On approximates the opening conditions by introducing a first-order lag in the flow response. The **Opening time constant** also impacts the modeled opening dynamics.

**Opening time constant — Valve opening time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state conditions when opening or closing the valve from one position to another. This parameter impacts the modeled opening dynamics.

**Dependencies**

To enable this parameter, set **Opening dynamics** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

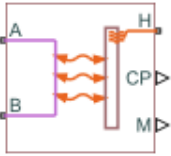
## See Also

Pressure Compensator Valve (IL) | Pressure-Compensated 3-Way Flow Control Valve (IL) | Pilot-Operated Check Valve (IL) | Cartridge Valve Insert (IL)

## Simple Heat Exchanger Interface (G)

Thermal interface between a gas and its surroundings

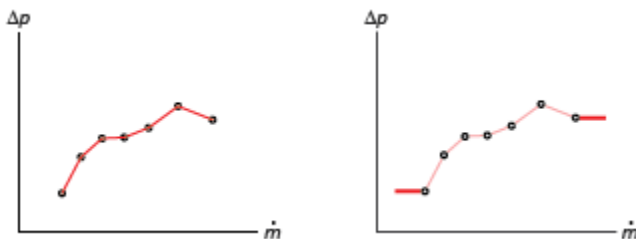
**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



### Description

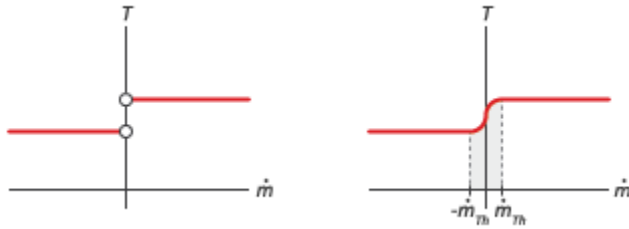
The Simple Heat Exchanger Interface (G) block models the pressure drop and temperature change in a gas as it traverses the length of a thermal interface such as that provided by a heat exchanger. Heat transfer across the thermal interface is ignored. See the composite block diagram of the Heat Exchanger (G-G) block for an example showing how to combine the two blocks.

The pressure drop is calculated as a function of mass flow rate from tabulated data specified at some reference pressure and temperature. The calculation is based on linear interpolation if the mass flow rate is within the bounds of the tabulated data and on nearest-neighbor extrapolation otherwise. In other words, neighboring data points connect through straight-line segments, with those at the mass flow rate bounds extending horizontally outward.



### Linear interpolation (left) and nearest-neighbor extrapolation (right)

The block calculations rely on the states and properties of the fluid—temperature, density, and specific internal energy—at the entrance to the thermal interface. The entrance changes abruptly from one port to the other during flow reversal, introducing discontinuities in the values of these variables. To eliminate these discontinuities, the block smooths the affected variables at mass flow rates below a specified threshold value.



### Smoothing of entrance temperature below mass flow rate threshold

#### Mass Balance

Mass can enter and exit the thermal interface through ports **A** and **B**. The volume of the interface is fixed but the compressibility of the fluid means that the mass inside the interface can change with pressure and temperature. The compressibility of the gas is always taken into account, with its value being that specified in the Gas Properties (G) block dialog box. The mass balance in the interface can then be expressed as:

$$\frac{\partial M}{\partial p} \frac{dp}{dt} + \frac{\partial M}{\partial T} \frac{dT}{dt} = \dot{m}_A + \dot{m}_B,$$

where:

- $M$  is the mass of the internal fluid volume of the thermal interface.
- $p$  is the internal fluid pressure.
- $T$  is the internal fluid temperature.
- $\dot{m}_*$  are the mass flow rates in through the gas ports.

#### Energy Balance

Energy can enter and exit the thermal interface in two ways: with fluid flow through ports **A** and **B** and with heat flow through port **H**. No work is done on or by the fluid inside the interface. The rate of energy accumulation in the internal fluid volume of the interface must therefore equal the sum of the energy flow rates through all three ports:

$$\frac{\partial E}{\partial p} \frac{dp}{dt} + \frac{\partial E}{\partial T} \frac{dT}{dt} = \phi_A + \phi_B + Q_H,$$

where:

- $E$  is the total energy in the internal fluid volume of the thermal interface.
- $\phi_*$  are the energy flow rates in through the gas ports.
- $Q$  is the heat flow rate in through the thermal port.

#### Momentum Balance

The pressure drop calculation is based entirely on tabulated data that you specify. The causes of the pressure drop are ignored, except in the effects that they might have on the specified data. The overall pressure drop from one gas port to the other is calculated from the individual pressure drops from each gas port to the internal fluid volume:

$$p_A - p_B = \Delta p_A - \Delta p_B,$$

where:

- $p_*$  are the fluid pressures at the gas ports.
- $\Delta p_*$  are the pressure drops from the gas ports to the internal fluid volume:

$$\Delta p_* = p_* - p,$$

with  $p$  as the pressure in the internal fluid volume.

The tabulated data is specified at a reference pressure and temperature from which a third reference parameter, the *reference density*, is calculated. The ratio of the reference density to the actual port density serves as a correction factor in the individual pressure drop equations, each defined as:

$$\Delta p_* = \Delta p(\dot{m}_*) \frac{\rho_R}{\rho_*},$$

where:

- $\Delta p(\dot{m})$  is the tabulated pressure drop function.
- $\rho_*$  are the fluid densities at the gas ports.

The asterisk denotes the gas port (**A** or **B**) at which a parameter or variable is defined. Subscript R denotes a reference value. The density at the interface entrance is smoothed below the mass flow rate threshold by introducing a hyperbolic term  $\alpha$ :

$$\rho_{*, \text{smooth}} = \rho_* \left( \frac{1 + \alpha}{2} \right) + \rho \left( \frac{1 - \alpha}{2} \right),$$

where  $\rho_{\text{smooth}}$  is the smoothed density at the entrance port,  $\rho_*$  is the unsmoothed density at the same port, and  $\rho$  is the density in the internal fluid volume. The hyperbolic smoothing term is defined as:

$$\alpha = \tanh \left( 4 \frac{\dot{m}_{\text{avg}}}{\dot{m}_{\text{th}}} \right),$$

where  $\dot{m}_{\text{avg}}$  is the average of the mass flow rates through the gas ports and  $\dot{m}_{\text{th}}$  is the mass flow rate threshold specified in the block dialog box. This threshold determines the width of the mass flow rate region over which to smooth the fluid density. The average mass flow rate is defined as:

$$\dot{m}_{\text{avg}} = \frac{\dot{m}_A + \dot{m}_B}{2}$$

## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables” and “Initial Conditions for Blocks with Finite Gas Volume”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Output

#### **CP – Isobaric specific heat of gas, kJ/(kg\*K)**

physical signal

Isobaric specific heat of the gas in the internal fluid volume of the thermal interface.

#### **M – Mass flow rate of the thermal liquid, kg/s**

physical signal

Mass flow rate of the gas in the internal fluid volume of the interface. The output signal is positive when the flow rate is directed from port **A** to port **B** and negative otherwise.

### Conserving

#### **A – Fluid opening**

gas

Opening through which gas can enter and exit the thermal interface.

#### **B – Fluid opening**

gas

Opening through which gas can enter and exit the thermal interface.

#### **H – Thermal condition at the fluid entrance**

thermal

Thermal port used to set the thermal condition at the gas port serving as the gas entrance.

## Parameters

### Pressure Loss

#### **Mass flow rate vector – Mass flow rates at which to specify pressure-drop data**

[.3, .5, 1, 1.5, 2, 2.5] kg/s (default) | *K*-element array with units of mass/time

Array of mass flow rates at which to specify the pressure drop tabulated data.

#### **Pressure drop vector – Pressure-drop data corresponding to specified mass flow rates**

[3, 5, 10, 25, 35, 50] \* 1e-3 MPa (default) | *K*-element array with units of pressure

Array of pressure drops from inlet to outlet corresponding to the tabulated mass flow rate data.

#### **Reference inflow temperature – Temperature at which pressure-drop data is specified**

293.15 K (default) | scalar with units of temperature

Temperature at which the tabulated pressure-drop data is specified.

#### **Reference inflow pressure – Pressure at which pressure-drop tabulated data is specified**

0.101325 MPa (default) | scalar with units of pressure



Pressure at which the tabulated pressure-drop data is specified. The block uses this parameter to calculate a third reference parameter, the reference density. The reference that it uses to scale the tabulated pressure drop data for pressures and temperatures deviating from the reference conditions.

**Mass flow rate threshold for flow reversal — Mass flow rate below which to smooth numerical data**

1e-6 kg/s (default) | scalar with units of mass/time

Mass flow rate below which to initiate a smooth flow reversal to prevent discontinuities in the simulation data.

**Gas volume — Volume of gas inside the heat exchanger**

0.01 m<sup>3</sup> (default) | scalar with units of volume

Volume of gas occupying the heat exchanger at any given time. The initial conditions specified in the **Effects and Initial Conditions** tab apply to this volume. The volume is constant during simulation.

**Cross-sectional area at ports A1 and B1 — Flow area at the gas inlets**

0.01 m<sup>2</sup> (default) | scalar with units of area

Flow area at the gas inlets. Inlets **A1** and **B1** are assumed to be identical in size.

## Version History

Introduced in R2017b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

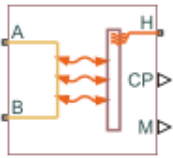
## See Also

Specific Dissipation Heat Transfer | Simple Heat Exchanger Interface (TL) | Heat Exchanger Interface (G)

## Simple Heat Exchanger Interface (TL)

Thermal interface between a thermal liquid and its surroundings

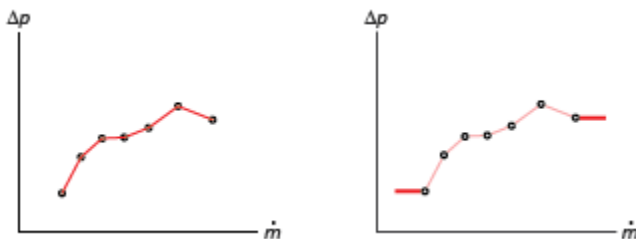
**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



### Description

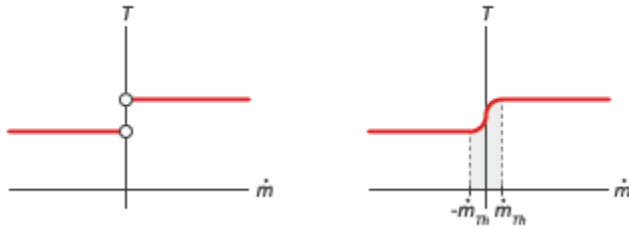
The Simple Heat Exchanger Interface (TL) block models the pressure drop and temperature change in a thermal liquid as it traverses the length of a thermal interface such as that provided by a heat exchanger. Heat transfer across the thermal interface is ignored. See the composite block diagram of the Heat Exchanger (TL-TL) block for an example showing how to combine the two blocks.

The pressure drop is calculated as a function of mass flow rate from tabulated data specified at some reference pressure and temperature. The calculation is based on linear interpolation if the mass flow rate is within the bounds of the tabulated data and on nearest-neighbor extrapolation otherwise. In other words, neighboring data points connect through straight-line segments, with those at the mass flow rate bounds extending horizontally outward.



### Linear interpolation (left) and nearest-neighbor extrapolation (right)

The block calculations rely on the states and properties of the fluid—temperature, density, and specific internal energy—at the entrance to the thermal interface. The entrance changes abruptly from one port to the other during flow reversal, introducing discontinuities in the values of these variables. To eliminate these discontinuities, the block smooths the affected variables at mass flow rates below a specified threshold value.



### Smoothing of entrance temperature below mass flow rate threshold

#### Mass Balance

Mass can enter and exit the thermal interface through ports **A** and **B**. The volume of the interface is fixed but the compressibility of the fluid means that the mass inside the interface can change with pressure and temperature. Whether compressibility is factored into the block calculations depends on the setting of the **Thermal Liquid dynamic compressibility** parameter in the **Effects and Initial Conditions** tab:

$$\dot{m}_A + \dot{m}_B = \begin{cases} \left( \frac{dp}{dt} \frac{1}{\beta} - \frac{dT}{dt} \alpha \right) \rho V, & \text{if } ThermalLiquiddynamiccompressibility \text{ is On} \\ 0, & \text{otherwise} \end{cases}$$

where:

- $\dot{m}_*$  are the mass flow rates in through the thermal liquid ports.
- $p$  is the internal fluid pressure.
- $T$  is the internal fluid temperature.
- $\alpha$  is the isobaric thermal expansion coefficient.
- $\beta$  is the isothermal bulk modulus.
- $\rho$  is the internal fluid density.
- $V$  is the internal fluid volume.

If the **Thermal Liquid dynamic compressibility** parameter is set to **Off**, the fluid is treated as incompressible and the mass flow rate in through one thermal liquid port must exactly equal that out through the other thermal liquid port. The rate of mass accumulation is, in this case, zero.

#### Energy Balance

Energy can enter and exit the thermal interface in two ways: with fluid flow through ports **A** and **B** and with heat flow through port **H**. No work is done on or by the fluid inside the interface. The rate of energy accumulation in the internal fluid volume of the interface must therefore equal the sum of the energy flow rates through all three ports:

$$\frac{\partial E}{\partial p} \frac{dp}{dt} + \frac{\partial E}{\partial T} \frac{dT}{dt} = \phi_A + \phi_B + Q_H$$

where:

- $E$  is the total energy in the internal fluid volume of the thermal interface.

- $\phi_*$  are the energy flow rates in through the thermal liquid ports.
- $Q$  is the heat flow rate in through the thermal port.

### Momentum Balance

The pressure drop calculation is based entirely on tabulated data that you specify. The causes of the pressure drop are ignored, except in the effects that they might have on the specified data. The overall pressure drop from one thermal liquid port to the other is calculated from the individual pressure drops from each thermal liquid port to the internal fluid volume:

$$p_A - p_B = \Delta p_A - \Delta p_B,$$

where:

- $p_*$  are the fluid pressures at the thermal liquid ports.
- $\Delta p_*$  are the pressure drops from the thermal liquid ports to the internal fluid volume:

$$\Delta p_* = p_* - p,$$

with  $p$  as the pressure in the internal fluid volume.

The tabulated data is specified at a reference pressure and temperature from which a third reference parameter, the *reference density*, is calculated. The ratio of the reference density to the actual port density serves as a correction factor in the individual pressure drop equations, each defined as:

$$\Delta p_* = \Delta p(\dot{m}_*) \frac{\rho_R}{\rho_*},$$

where:

- $\Delta p(\dot{m})$  is the tabulated pressure drop function.
- $\rho_*$  are the fluid densities at the thermal liquid ports.

The asterisk denotes the thermal liquid port (**A** or **B**) at which a parameter or variable is defined. Subscript R denotes a reference value. The density at the interface entrance is smoothed below the mass flow rate threshold by introducing a hyperbolic term  $\alpha$ :

$$\rho_{*, \text{smooth}} = \rho_* \left( \frac{1 + \alpha}{2} \right) + \rho \left( \frac{1 - \alpha}{2} \right),$$

where  $\rho_{\text{smooth}}$  is the smoothed density at the entrance port,  $\rho_*$  is the unsmoothed density at the same port, and  $\rho$  is the density in the internal fluid volume. The hyperbolic smoothing term is defined as:

$$\alpha = \tanh \left( 4 \frac{\dot{m}_{\text{avg}}}{\dot{m}_{\text{th}}} \right),$$

where  $\dot{m}_{\text{avg}}$  is the average of the mass flow rates through the thermal liquid ports and  $\dot{m}_{\text{th}}$  is the mass flow rate threshold specified in the block dialog box. This threshold determines the width of the mass flow rate region over which to smooth the fluid density. The average mass flow rate is defined as:

$$\dot{m}_{\text{avg}} = \frac{\dot{m}_A + \dot{m}_B}{2}$$

## Ports

### Output

#### **CP – Isobaric specific heat of the thermal liquid, kJ/(kg\*K)**

physical signal

Isobaric specific heat of the thermal liquid in the internal fluid volume of the thermal interface.

#### **M – Mass flow rate of the thermal liquid, kg/s**

physical signal

Mass flow rate of the thermal liquid in the interior of the thermal interface. The output signal is positive when the flow rate is directed from port **A** to port **B** and negative otherwise.

### Conserving

#### **A – Fluid opening**

thermal liquid

Opening through which thermal liquid can enter and exit the thermal interface.

#### **B – Fluid opening**

thermal liquid

Opening through which thermal liquid can enter and exit the thermal interface.

#### **H – Thermal condition at the fluid entrance**

thermal

Thermal port used to set the thermal condition at the thermal liquid port serving as the thermal liquid entrance.

## Parameters

### Pressure Loss Tab

#### **Mass flow rate vector – Mass flow rates at which to specify pressure-drop data**

[.3, .5, 1, 1.5, 2, 2.5] kg/s (default) | *K*-element array with units of mass/time

Array of mass flow rates at which to specify the pressure drop tabulated data.

#### **Pressure drop vector – Pressure-drop data corresponding to specified mass flow rates**

[3, 5, 10, 25, 35, 50] \* 1e-3 MPa (default) | *K*-element array with units of pressure

Array of pressure drops from inlet to outlet corresponding to the tabulated mass flow rate data.

#### **Reference inflow temperature – Temperature at which pressure-drop data is specified**

293.15 K (default) | scalar with units of temperature

Temperature at which the tabulated pressure-drop data is specified.

#### **Reference inflow pressure – Pressure at which pressure-drop tabulated data is specified**

0.101325 MPa (default) | scalar with units of pressure

Pressure at which the tabulated pressure-drop data is specified. The block uses this parameter to calculate a third reference parameter, the reference density. The reference that it uses to scale the tabulated pressure drop data for pressures and temperatures deviating from the reference conditions.

**Mass flow rate threshold for flow reversal – Mass flow rate below which to smooth numerical data**

1e-6 kg/s (default) | scalar with units of mass/time

Mass flow rate below which to initiate a smooth flow reversal to prevent discontinuities in the simulation data.

**Thermal Liquid volume – Volume of thermal liquid inside the heat exchanger**

0.01 m<sup>3</sup> (default) | scalar with units of volume

Volume of thermal liquid occupying the heat exchanger at any given time. The initial conditions specified in the **Effects and Initial Conditions** tab apply to this volume. The volume is constant during simulation.

**Cross-sectional area at ports A1 and B1 – Flow area at the thermal liquid inlets**

0.01 m<sup>2</sup> (default) | scalar with units of area

Flow area at the thermal liquid inlets. Inlets **A1** and **B1** are assumed to be identical in size.

**Effects and Initial Conditions**

**Thermal Liquid dynamic compressibility – Option to model pressure dynamics inside the heat exchanger**

On (default) | Off

Option to model the pressure dynamics inside the heat exchanger. Setting this parameter to Off removes the pressure derivative terms from the component energy and mass conservation equations. The pressure inside the heat exchanger is then reduced to the weighted average of the two port pressures.

**Thermal Liquid initial temperature – Temperature inside the heat exchanger at the start of simulation**

293.15 K (default) | scalar with units of temperature

Temperature of the internal volume of thermal liquid at the start of simulation.

**Thermal Liquid initial pressure – Pressure inside the heat exchanger at the start of simulation**

0.101325 MPa (default) | scalar with units of pressure

Pressure of the internal volume of thermal liquid at the start of simulation.

## Version History

Introduced in R2017b

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Specific Dissipation Heat Transfer | Heat Exchanger Interface (TL) | Simple Heat Exchanger Interface (G) | Heat Exchanger (TL)

## Single-Acting Actuator (TL)

Single-acting linear actuator in a thermal liquid system

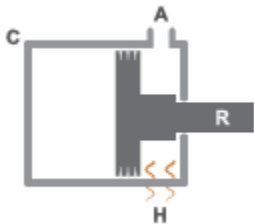
**Library:** Simscape / Fluids / Thermal Liquid / Actuators



### Description

The Single-Acting Actuator (TL) block represents a linear actuator with piston motion controlled by a single thermal liquid chamber. The actuator generates force in the extension and retraction strokes, but the actuation force depends on the gauge pressure at a single chamber.

The figure shows the key components of an actuator. Port **A** represents the thermal liquid chamber inlet. Port **R** represents the translating actuator piston, and port **C** represents the actuator case. Port **H** represents the thermal interface between the thermal liquid chamber and the environment.



### Single-Acting Actuator Schematic

#### Displacement

The block measures the piston displacement as the position at port **R** relative to port **C**. The **Mechanical orientation** parameter identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the value of the **Dead volume** parameter. When you input the piston displacement using port **p**, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when you use a Translational Multibody Interface block connection to a Simscape Multibody joint.

The direction of the piston motion depends on the **Mechanical orientation** parameter. If the mechanical orientation is positive, then a positive gauge pressure at port **A** yields a positive piston translation relative to the actuator case. The direction of motion reverses for a negative mechanical orientation.

#### Hard Stop

A set of hard stops limit the piston range of motion. The block uses an implementation of the Translational Hard Stop block, which treats hard stops like spring-damper systems. The spring stiffness coefficient controls the restorative component of the hard-stop contact force and the damping coefficient the dissipative component.

The hard stops are located at the distal ends of the piston stroke. If the mechanical orientation is positive, then the lower hard stop is at  $x = 0$ , and the upper hard stop is at  $x = +stroke$ . If the

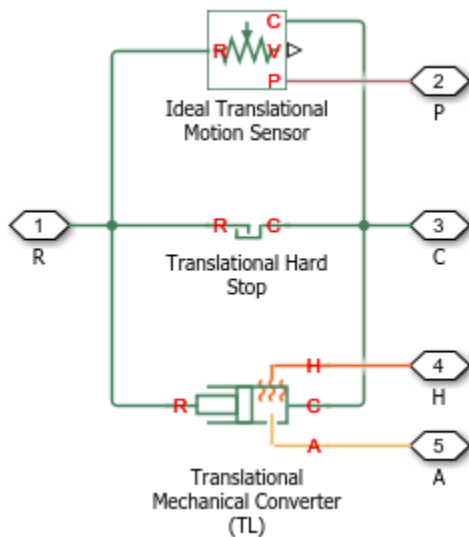


mechanical orientation is negative, then the lower hard stop is at  $x = -stroke$ , and the upper hard stop is at  $x = 0$ .

### Block Composite

This block is a composite component based on the Simscape Foundation blocks:

- Translational Mechanical Converter (TL)
- Translational Hard Stop
- Ideal Translational Motion Sensor



### Composite Component Diagram

## Ports

### Input

#### **p** – Multibody piston position input, m

physical signal

Physical signal input associated with the piston position, in m. Connect this port to a Simscape Multibody network using a Translational Multibody Interface block.

### Dependencies

To enable this port, set **Piston displacement** to Provide input signal from Multibody joint.

### Output

#### **p** – Piston position, m

physical signal

Physical signal output associated with the piston position, in m.

**Dependencies**

To enable this port, set **Piston displacement** to Calculate from velocity of port R relative to port C.

**Conserving****A — Liquid port**

thermal liquid

Thermal liquid conserving port associated with chamber A.

**C — Actuator casing**

translational mechanical

Translational mechanical conserving port associated with the actuator casing.

**R — Actuator piston**

translational mechanical

Translational mechanical conserving port associated with the actuator piston.

**H — Heat transfer**

thermal liquid

Thermal liquid conserving port associated with the thermal mass of the liquid volume.

**Parameters****Actuator****Mechanical orientation — Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C, the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C, the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

**Piston cross-sectional area — Cross-sectional area of piston rod**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the piston rod.

**Piston stroke — Maximum piston travel distance**

0.1 m (default) | positive scalar

Maximum piston travel distance.

**Dead volume – Fluid volume at full piston retraction**1e-5 m<sup>3</sup> (default) | positive scalar

Volume of liquid when the piston displacement is 0. This is the liquid volume when the piston is up against the actuator end cap.

**Environment pressure specification – Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. When you select Atmospheric pressure, the block assumes a pressure of 0.101325 MPa.

**Environment pressure – User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Hard Stop****Hard-stop stiffness coefficient – Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient.

**Hard-stop damping coefficient – Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient.

**Hard stop model – Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

**Transition region – Application range of hard stop force model**

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of this range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

**Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

## Initial Conditions

### Piston displacement — Method for determining piston position

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the piston position. The block can receive the position from a Multibody block when set to Provide input signal from Multibody joint, or calculates the position internally and reports the position at port **p**. The position is between 0 and the **Piston stroke** when the mechanical orientation is positive and 0 and **-Piston stroke** when the mechanical orientation is negative.

### Initial piston displacement — Piston position at start of simulation

0 m (default) | scalar

Piston position at the start of the simulation.

### Dependencies

To enable this parameter, set **Piston displacement** to Calculate from velocity of port R relative to port C.

### Fluid dynamic compressibility — Whether to model fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

### Initial liquid temperature — Starting liquid temperature

293.15 K (default)

Initial temperature of the liquid volume in the actuator.

### Initial liquid pressure — Starting liquid pressure for compressible fluids

0.101325 MPa (default) | positive scalar

Starting liquid pressure for compressible fluids.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

## Version History

Introduced in R2016a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Double-Acting Actuator (TL)

## **Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”

# Single-Acting Hydraulic Cylinder

Hydraulic actuator exerting force in one direction



## Library

Hydraulic Cylinders

### Description

The Single-Acting Hydraulic Cylinder block models a device that converts hydraulic energy into mechanical energy in the form of translational motion. Hydraulic fluid pumped under pressure into the cylinder chamber forces the piston to move and exert force on the cylinder rod. Single-acting cylinders transfer force and motion in one direction only. Use an external device, such as a spring, weight, or another opposite installed cylinder, to move the rod in the opposite direction.

Ports **R** and **C** are mechanical translational conserving ports corresponding to the cylinder rod and cylinder clamping structure, respectively. Port **A** is a hydraulic conserving port associated with the cylinder inlet.

The energy through port **A** is directed to the Translational Hydro-Mechanical Converter block. The converter transforms hydraulic energy into mechanical energy and accounts for the fluid compressibility in the cylinder chamber. The rod motion is limited with the mechanical Translational Hard Stop block in such a way that the rod can travel only between cylinder caps. The piston position is conveyed to the physical signal port **p**.

### Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Cylinder orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the chamber dead volume. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

When displacement is set by the cylinder, it is calculated as:

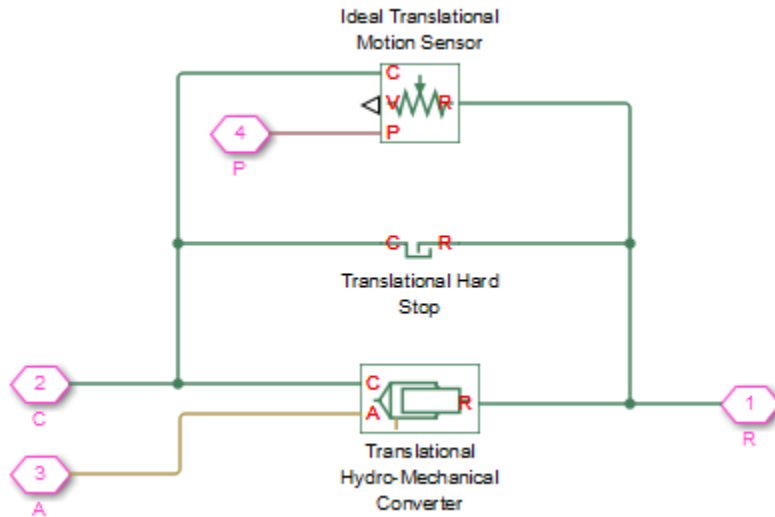
$$x_{\text{pst}} = x_0 + x_p \quad (1-11)$$

where

$x_{\text{pst}}$	Rod displacement output by the physical signal port
$x_0$	Initial distance between piston and cap
$x_p$	Rod displacement with respect to its initial position

## Composite Structure

The model of the cylinder is built of Simscape Foundation library blocks. The schematic diagram of the model is shown below.



## Basic Assumptions and Limitations

- No leakage, internal or external, is taken into account.
- No loading on piston rod, such as inertia, friction, spring, and so on, is taken into account. If necessary, you can easily add them by connecting an appropriate building block to cylinder port R.

## Parameters

### Piston area

Effective piston area. The default value is  $0.001 \text{ m}^2$ .

### Piston stroke

Piston maximum travel between caps. The default value is  $0.1 \text{ m}$ .

### Piston displacement

Method for determining the piston position. The default value is `Calculate from velocity of port R relative to port C`, which calculates the position internally and reports the position at port **p**. The block can also receive the position at port **p** from a Multibody block when set to `Provide input signal from Multibody joint`.

### Initial distance between piston and cap

The distance between the piston and cap at the beginning of simulation. This value cannot exceed the piston stroke. The default value is  $0$ , which corresponds to the fully retracted position. To enable this parameter, set **Piston displacement** to `Calculate from velocity of port R relative to port C`.

### Dead volume

Fluid volume that remains in the chamber after the rod is fully retracted. The default value is  $1e-4 \text{ m}^3$ .

**Chamber initial pressure**

Pressure in the cylinder chamber at the beginning of simulation. The default value is 0.

**Specific heat ratio**

Gas-specific heat ratio for the Hydraulic Piston Chamber block. The default value is 1.4.

**Contact stiffness**

Specifies the elastic property of colliding bodies for the Translational Hard Stop block. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is 1e6 N/m.

**Contact damping**

Specifies dissipating property of colliding bodies for the Translational Hard Stop block. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, MathWorks recommends that you assign a nonzero value to this parameter. The default value is 150 N\*s/m.

**Hard stop model**

Modeling approach for hard stops. Options include:

- **Stiffness and damping applied smoothly through transition region (default)** — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- **Full stiffness and damping applied at bounds, undamped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- **Full stiffness and damping applied at bounds, damped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied. This is the hard-stop model used in previous releases.

**Transition region**

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value specified here. It is at its full value when the distance to the hard stop is zero. The default value is 1 mm.

**Cylinder orientation**

Specifies cylinder orientation with respect to the globally assigned positive direction. The cylinder can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A exerts force in negative direction, set the parameter to `Pressure at A causes negative displacement of R relative to C`. The default value is `Pressure at A causes positive displacement of R relative to C`.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:



- **Cylinder orientation**

All other block parameters are available for modification.

## Global Parameters

Parameter determined by the type of working fluid:

- **Fluid bulk modulus**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the cylinder inlet.

R

Mechanical translational conserving port associated with the cylinder rod.

C

Mechanical translational conserving port associated with the cylinder clamping structure.

p

Physical signal input port that receives rod extension from a Multibody block. To expose this port, set **Piston displacement** to Provide input signal from Multibody joint.

p

Physical signal output port that returns the rod position with respect to port C. To expose this port, set **Piston displacement** to Calculate from velocity of port R relative to port C.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Single-Acting Hydraulic Cylinder (Simple) | Double-Acting Hydraulic Cylinder | Ideal Translational Motion Sensor | Translational Hard Stop | Translational Hydro-Mechanical Converter

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Single-Acting Actuator (IL)

Single-acting linear actuator in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators



## Description

The Single-Acting Actuator (IL) block represents an actuator that converts the liquid pressure at port **A** into a mechanical force at port **R** via an extending-retracting piston. The piston motion is limited by a hard stop model. When the piston position is calculated internally, it is reported at port **p**, and when the position is set by a connection to a Simscape Multibody joint, it is received as a physical signal at port **p**.

The **Initial piston displacement**, **Fluid dynamic compressibility**, and reference environmental pressure can be modified. Fluid and mechanical inertia are not modeled.

## Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the **Dead volume**. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Translational Multibody Interface block connection to a Simscape Multibody joint.

## Hard Stop Model

Three models are available to model the extension limit of the actuator piston. This block uses a similar formulation as the Translational Hard Stop block and models uniform damping and stiffness coefficients at both ends of the piston stroke. For more information on the hard stop model options, see the Translational Hard Stop block.

The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Piston stroke** or **Piston initial displacement**. Outside of this region,  $F_{HardStop} = 0$ .

## Cushion

You can optionally model cushioning toward the extremes of the piston stroke. Setting **Cylinder end cushioning** to On slows the piston motion as it approaches its maximum extension, which is defined in **Piston stroke**. For more information on the functionality of a cylinder cushion, see the Cylinder Cushion (IL) block.

## Friction

You can optionally model friction against piston motion. When **Cylinder friction** is set to On, the resulting friction is a combination of Stribeck, Coulomb, and viscous effects. The pressure difference is measured between the chamber pressure and the environment pressure. For more information on the friction model and its limitations, see the Cylinder Friction block.

## Leakage

You can optionally model leakage between the liquid chamber and the piston reservoir. When **Leakage** is set to **On**, Poiseuille flow is modeled between the piston and cylinder. This block uses the Simscape Foundation Library Laminar Leakage (IL) block. The flow rate is calculated as:

$$\dot{m} = \frac{\frac{\pi}{128} \left( d_0^4 - d_i^4 - \frac{(d_0^2 - d_i^2)^2}{\log(d_0/d_i)} \right)}{\nu L} (p_A - p_{env}),$$

where:

- $\nu$  is the fluid kinematic viscosity.
- $L$  is the piston length,  $\mathbf{p} - P_0$ .
- $p_A$  is the pressure at port **A**.
- $p_{env}$  is the environmental pressure, which is selected in the **Environment pressure specification** parameter.

The cylinder diameter,  $d_0$ , is  $d_0 = d_i + 2c$ , where  $c$  is the **Piston-cylinder clearance**, and the piston diameter,  $d_i$ , is  $d_i = \sqrt{\frac{4A_P}{\pi}}$ , where  $A_P$  is the **Piston cross-sectional area**.

## Numerically-Smoothed Area and Pressure

At the extremes of the cushion orifice area and check valve pressure range, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to all calculated areas and valve pressures, but primarily influences the simulation at the extremes of these ranges.

The normalized orifice area is calculated as:

$$\widehat{A} = \frac{(A - A_{leak})}{(A_{max} - A_{leak})}.$$

where:

- $A_{leak}$  is the cushion **Leakage area between plunger and cushion sleeve**.
- $A_{max}$  is the **Cushion plunger cross-sectional area**.

The **Smoothing factor**,  $f$ , is applied to the normalized area:

$$\widehat{A}_{smoothed} = \frac{1}{2} + \frac{1}{2} \sqrt{\widehat{A}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2} \sqrt{(\widehat{A} - 1)^2 + \left(\frac{f}{4}\right)^2}.$$

The smoothed orifice area is:

$$A_{smoothed} = \widehat{A}_{smoothed}(A_{max} - A_{leak}) + A_{leak}.$$

Similarly, the normalized valve pressure is:

$$\widehat{p} = \frac{(p - p_{cracking})}{(p_{max} - p_{cracking})}.$$

where:

- $p_{cracking}$  is the cushion **Check valve cracking pressure differential**.
- $p_{max}$  is the cushion **Check valve maximum pressure differential**.

Smoothing applied to the normalized pressure is:

$$\widehat{p}_{smoothed} = \frac{1}{2} + \frac{1}{2}\sqrt{\widehat{p}^2 + \left(\frac{f}{4}\right)^2} - \frac{1}{2}\sqrt{(\widehat{p} - 1)^2 + \left(\frac{f}{4}\right)^2},$$

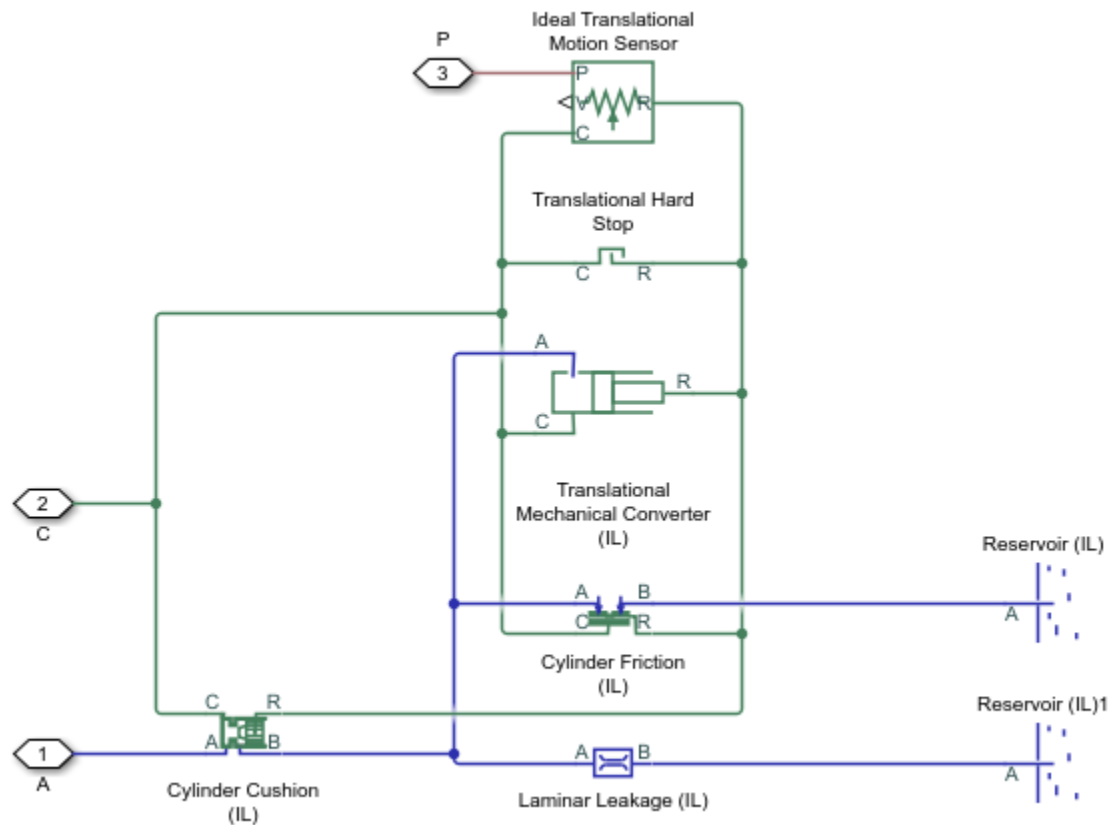
and the smoothed pressure is:

$$p_{smoothed} = \widehat{p}_{smoothed}(p_{max} - p_{cracking}) + p_{cracking}.$$

### **Block Sub-Components**

The Single-Acting Actuator (IL) block comprises four Simscape Foundation and two Fluids Library blocks:

- Translational Hard Stop
- Laminar Leakage (IL)
- Converter
- Sensor
- Cylinder Cushion (IL)
- Cylinder Friction (IL)



## Actuator Structural Diagram

## Ports

### Input

#### **p** – Multibody piston position input, m

physical signal

Physical signal input port associated with the piston position, in m. Connect this port to a Simscape Multibody block.

### Dependencies

To enable this port, set **Piston displacement** to Provide input signal from Multibody joint.

### Output

#### **p** – Piston position, m

physical signal

Piston position in m, returned as a physical signal.

**Dependencies**

To expose this port, set **Piston displacement** to Calculate from velocity of port R relative to port C.

**Conserving****A – Liquid port**

isothermal liquid

Thermal liquid conserving port associated with chamber A.

**C – Actuator casing**

translational mechanical

Translational mechanical conserving port associated with the actuator casing.

**R – Actuator piston**

translational mechanical

Translational mechanical conserving port associated with the actuator piston.

**Parameters****Actuator****Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

**Piston cross-sectional area – Cross-sectional area of piston rod**

$0.01 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the piston rod.

**Piston stroke – Maximum piston travel distance**

$0.1 \text{ m}$  (default) | positive scalar

Maximum piston travel distance.

**Dead volume – Fluid volume at full piston retraction**

$1\text{e-}5 \text{ m}^3$  (default) | positive scalar

Volume of liquid when the piston displacement is 0. This is the liquid volume when the piston is up against the actuator end cap.

**Environment pressure specification — Reference environment pressure**

Atmospheric pressure (default) | Specified pressure

Environment reference pressure. The Atmospheric pressure option sets the environmental pressure to 0.101325 MPa.

**Environment pressure — User-defined environmental pressure**

0.101325 MPa (default) | positive scalar

User-defined environmental pressure.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Hard Stop****Hard-stop stiffness coefficient — Stiffness coefficient**

1e10 N/m (default) | positive scalar

Piston stiffness coefficient.

**Hard-stop damping coefficient — Damping coefficient**

150 N/(m/s) (default) | positive scalar

Piston damping coefficient. This value must be greater than 0.

**Hard stop model — Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Translational Hard Stop block for more information.

**Transition region — Application range of hard stop force model**

0.1 mm (default) | positive scalar

Application range of the hard stop force model. Outside of this range of the piston maximum extension and piston maximum retraction, the **Hard stop model** is not applied and there is no additional force on the piston.

**Dependencies**

To enable this parameter, set **Hard stop model** to Stiffness and damping applied smoothly through transition region, damped rebound.

**Cushion****Cylinder end cushioning — Whether to model piston slow-down at maximum extension**

Off (default) | On

Whether to model piston slow-down at maximum extension. See the Cylinder Cushion (IL) block for more information.

**Cushion plunger cross-sectional area — Cylinder cushion plunger area**1e-4 m<sup>2</sup> (default) | positive scalar

Area of the plunger inside the actuator cushion element.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Cushion plunger length — Length of cushion plunger**

1e-3 m (default) | positive scalar

Length of the cushion plunger.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Cushion orifice area — Area of orifice between cushion chambers**

1e-6 m<sup>2</sup> (default) | positive scalar

Area of the orifice between cushion chambers.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Leakage area between plunger and cushion sleeve — Gap between cushion plunger and sleeve**

1e-7 m<sup>2</sup> (default) | positive scalar

Gap area between the cushion plunger and sleeve. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Check valve cracking pressure differential — Cushion threshold pressure**

0.01 MPa (default) | positive scalar

Pressure beyond which the valve operation is triggered. When the pressure difference between port **A** and  $P_{env}$  meets or exceeds the **Check valve cracking pressure differential**, the cushion valve begins to open.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Check valve maximum pressure differential — Cushion differential pressure maximum**

0.1 MPa (default) | positive scalar

Maximum cushion valve differential pressure. This parameter provides an upper limit to the pressure so that system pressures remain realistic.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to 0n.

**Check valve maximum area — Area of fully opened cushion valve**

1e-4 m<sup>2</sup> (default) | positive scalar



Cross-sectional area of the cushion valve in its fully open position.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to On.

**Check valve leakage area — Cushion valve gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the cushion check valve is in a fully closed position. Any area smaller than this value is saturated to the specified leakage area. This value contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to On.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the variable orifice and check valve are in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Cylinder end cushioning** to On.

**Friction**

**Cylinder friction — Whether to model friction against piston motion**

Off (default) | On

Whether to model friction against piston motion. The model accounts for Coulomb, Stribeck, and viscous friction. See the Cylinder Friction block for more information.

**Breakaway to Coulomb friction force ratio — Ratio of breakaway force to Coulomb friction force**

1.2 (default) | positive scalar

Ratio of the breakaway force to the Coulomb friction force.

**Dependencies**

To enable this parameter, set **Cylinder friction** to On.

**Breakaway friction velocity — Threshold for motion**

0.1 m/s (default) | positive scalar

Threshold velocity for motion against friction force to begin.

**Dependencies**

To enable this parameter, in the **Friction** tab, set **Cylinder friction** to On.

**Preload force — Initial force in cylinder due to seal assembly**

20 N (default) | scalar

Initial force in the cylinder due to seal assembly.

**Dependencies**

To enable this parameter, set **Cylinder friction** to On.

**Coulomb friction force coefficient – Coulomb friction force coefficient**

1e-6 N/Pa (default) | positive scalar

Coulomb force coefficient of friction.

**Dependencies**

To enable this parameter, set **Cylinder friction** to On.

**Viscous friction coefficient – Viscous friction coefficient**

100 N/(m/s) (default) | positive scalar

Viscous friction coefficient.

**Dependencies**

To enable this parameter, set **Cylinder friction** to On.

**Leakage****Leakage – Whether to model annular leakage**

Off (default) | On

Whether to model annular leakage between the fluid chamber and the piston reservoir at reference environment conditions. The leakage is considered laminar. See the Laminar Leakage (IL) block for more information.

**Piston-cylinder clearance – Radial clearance**

1e-4 m (default) | positive scalar

Radial distance between the piston rod and cylinder casing.

**Dependencies**

To enable this parameter, set **Leakage** to On.

**Piston head length – Annular length of piston mounting**

0.01 m (default) | positive scalar

Annular length of the piston mounting, not including the piston rod.

**Dependencies**

To enable this parameter, set **Leakage** to On.

**Initial conditions****Piston displacement – Method for determining piston position**

Calculate from velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the piston position. The block can receive the position from a Multibody block when set to Provide input signal from Multibody joint, or calculates the position

internally and reports the position at port **p**. The position is between 0 and the **Piston stroke** when the mechanical orientation is positive and 0 and **-Piston stroke** when the mechanical orientation is negative.

### **Initial piston displacement – Piston position at start of simulation**

0 m (default) | scalar

Piston position at the start of the simulation.

#### **Dependencies**

To enable this parameter, set **Piston displacement** to Calculate from velocity of port R relative to port C.

### **Fluid dynamic compressibility – Whether to model fluid compressibility**

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

### **Initial liquid pressure – Starting liquid pressure for compressible fluids**

0.101325 MPa (default) | positive scalar

Starting liquid pressure for compressible fluids.

#### **Dependencies**

To enable this parameter, set **Fluid dynamic compressibility** to On.

## **Version History**

Introduced in R2020a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Rotating Single-Acting Actuator (IL) | Single-Acting Rotary Actuator (IL) | Pilot Valve Actuator (IL) | Double-Acting Actuator (IL) | Double-Acting Actuator (G-IL)

## **Topics**

“Connecting Simscape Networks to Simscape Multibody Joints”

## Single-Acting Hydraulic Cylinder (Simple)

Basic functionality of single-acting hydraulic cylinder



### Library

Hydraulic Cylinders

### Description

The Single-Acting Hydraulic Cylinder (Simple) block represents a simplified version of a hydraulic cylinder, developed for applications where only the basic cylinder functionality must be reproduced, in exchange for better numerical efficiency. For these reasons, such factors as fluid compressibility, friction, and leakages are assumed to be negligible. The hard stops are assumed to be fully inelastic, to eliminate any possible oscillations at the end of the stroke. The model is especially suitable for real-time and HIL (hardware-in-the-loop) simulation, if such simplifications are acceptable.

The model is described with the following equations:

$$F = A \cdot p - F_c$$

$$q = A \cdot v$$

$$\frac{dx}{dt} = v$$

$$v = v_R - v_C$$

$$F_c = \begin{cases} (x - x_E) \cdot K_p \cdot v & \text{if } x > x_E, v > 0 \\ (x - x_R) \cdot K_p \cdot v & \text{if } x < x_R, v < 0 \\ 0 & \text{otherwise} \end{cases}$$

$$x_E = S - x_0$$

$$x_R = -x_0$$

where

$F$	Force developed by the cylinder
$v$	Cylinder rod velocity
$v_R, v_C$	Absolute velocities of cylinder rod and cylinder case, respectively
$A$	Piston area
$p$	Pressure at the cylinder inlet

$q$	Flow rate at the cylinder inlet
$x$	Piston position
$x_0$	Initial distance between piston and the cap
$F_c$	Hard stop force
$x_E$	Distance the piston can travel to fully extend from initial position
$x_R$	Distance the piston can travel to fully retract from initial position
$K_p$	Penetration coefficient
$S$	Piston stroke

The main difference between this block and the Single-Acting Hydraulic Cylinder block is the representation of the hard stop:

- The Single-Acting Hydraulic Cylinder block utilizes the elastic model of the stop, which is essentially a combination of a spring and a damper, connected in parallel. The stiffness of the spring, which represents contact stiffness of colliding bodies, is very high, resulting in high-frequency, low-magnitude oscillations at the moment the bodies collide. These oscillations can hardly be noticed experimentally, but they are difficult to process by a numerical simulation and generally decrease numerical efficiency.
- The hard stop in the Single-Acting Hydraulic Cylinder (Simple) block is represented with the inelastic model, which is essentially a viscous damper with the penetration-dependent damping coefficient. This coefficient is referred to as the penetration coefficient. With inelastic model, no oscillation is generated during an impact, resulting in improved numerical robustness and efficiency. But inelastic stop model has a feature that you must consider while selecting the model: colliding bodies continue slowly moving into each other as long as the contact is loaded with the compressing force. In real life, this phenomenon is similar to collision of two bodies separated by a sizable layer of viscous liquid. It takes some time to squeeze the liquid before bodies themselves come into contact.

Connections R and C are mechanical translational conserving ports corresponding to the cylinder rod and cylinder clamping structure, respectively. Connection A is a hydraulic conserving port associated with the cylinder inlet. The physical signal output port P shows current rod extension.

Pressure at port A generates force in the direction specified by the **Cylinder orientation** parameter.

## Basic Assumptions and Limitations

- Friction between moving parts is not taken into account.
- Inertia effects are not taken into account.
- Fluid compressibility is not taken into account.
- Leakage flows are assumed to be negligible.
- The hard stops are assumed to be fully inelastic, as explained above.

## Parameters

### Piston area

Effective piston area. The default value is  $5e-4 \text{ m}^2$ .

**Piston stroke**

Piston maximum travel between caps. The default value is 0.1 m.

**Initial distance between piston and cap**

The distance between the piston and cap at the beginning of simulation. This value cannot exceed the piston stroke. The default value is 0, which corresponds to the fully retracted position.

**Penetration coefficient**

Specifies the penetration property of colliding bodies. The higher the value of the coefficient, the less the bodies penetrate into each other, but the sharper the increase of the impact force. To find out the value of the coefficient for a particular application, it is recommended to run the same model with different hard stop models (or with different cylinder models) until they show close results. The default value of the coefficient is 1e12 N/m/(m/s).

**Cylinder orientation**

Specifies cylinder orientation with respect to the globally assigned positive direction. The cylinder can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A exerts force in negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Cylinder orientation**

All other block parameters are available for modification.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the cylinder inlet.

R

Mechanical translational conserving port associated with the cylinder rod.

C

Mechanical translational conserving port associated with the cylinder clamping structure.

P

Physical signal output port that outputs rod extension.

**Version History**

Introduced in R2010a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Double-Acting Hydraulic Cylinder | Double-Acting Hydraulic Cylinder (Simple) | Single-Acting Hydraulic Cylinder | Translational Hard Stop | Translational Hydro-Mechanical Converter

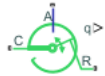
## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Single-Acting Rotary Actuator (IL)

Double-acting rotary actuator in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Actuators



## Description

The Single-Acting Rotary Actuator (IL) block models a rotary actuator that converts liquid pressure into mechanical torque in an isothermal liquid network. The motion of the piston when it is near full extension or full retraction is limited by one of three hard stop models.

Port **A** is the isothermal liquid conserving port associated with inlet of the liquid chamber. Ports **R** and **C** are the mechanical rotational conserving ports associated with the rotating shaft and the actuator casing, respectively. If **Mechanical orientation** is set to **Pressure at A causes positive rotation of R relative to C**, the pressure in the liquid chamber causes a positive rotation of the shaft at port **R** relative to port **C**. When the shaft angle is calculated internally, the physical signal port **q** reports the angle. When the angle is set by a connection to a Simscape Multibody joint, it is received as a physical signal at port **q**.

## Displacement

The piston displacement is measured as the position at port **R** relative to port **C**. The **Mechanical orientation** identifies the direction of piston displacement. The piston displacement is neutral, or  $\theta$ , when the chamber volume is equal to the **Dead volume**. When displacement is received as an input, ensure that the derivative of the position is equal to the piston velocity. This is automatically the case when the input is received from a Rotational Multibody Interface block connection to a Simscape Multibody joint.

## Hard Stop Model

To avoid mechanical damage to an actuator when it is fully extended or fully retracted, an actuator typically displays nonlinear behavior when the piston approaches these limits. The Single-Acting Rotary Actuator (IL) block models this behavior with a choice of three hard stop models, which model the material compliance through a spring-damper system. The hard stop models are:

- Stiffness and damping applied smoothly through transition region, damped rebound.
- Full stiffness and damping applied at bounds, undamped rebound.
- Full stiffness and damping applied at bounds, damped rebound.

The hard stop force is modeled when the piston is at its upper or lower bound. The boundary region is within the **Transition region** of the **Stroke** or piston initial displacement. Outside of this region,  $F_{HardStop} = 0$ .

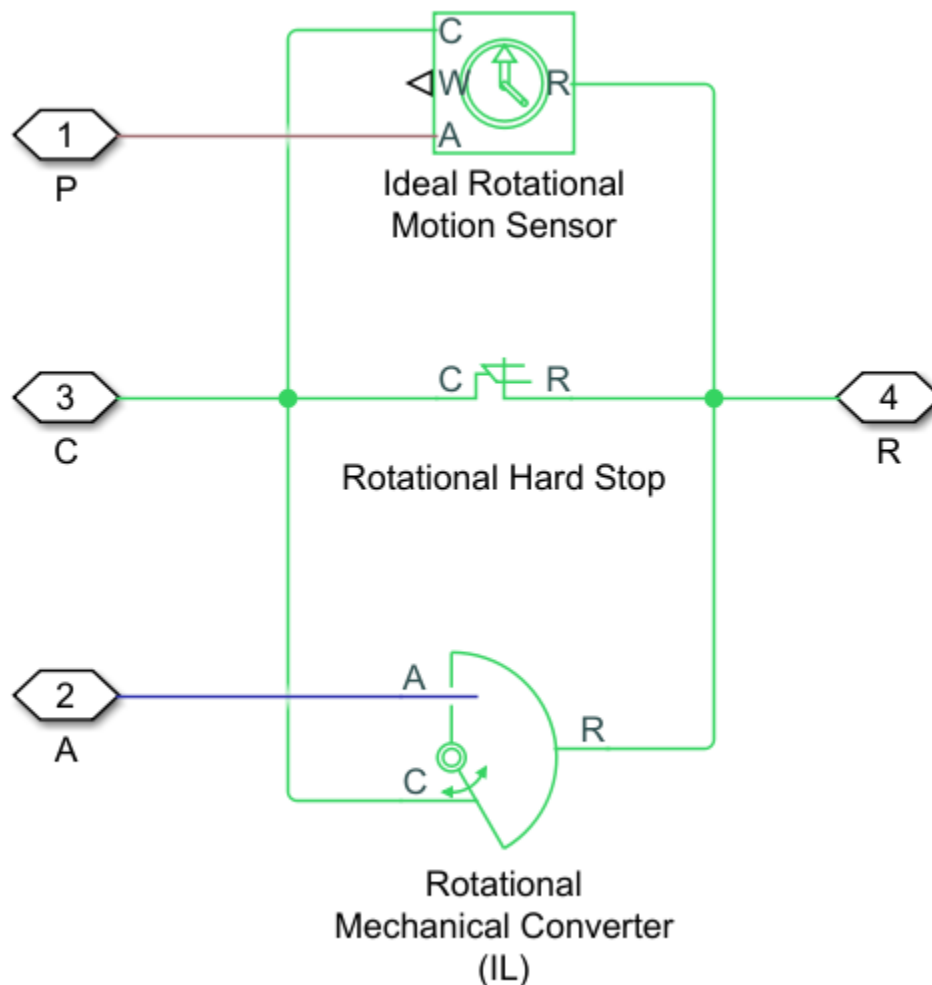
For more information about these settings, see the Rotational Hard Stop block page.



## Block Schematics

The actuator block comprises three Foundation Library blocks:

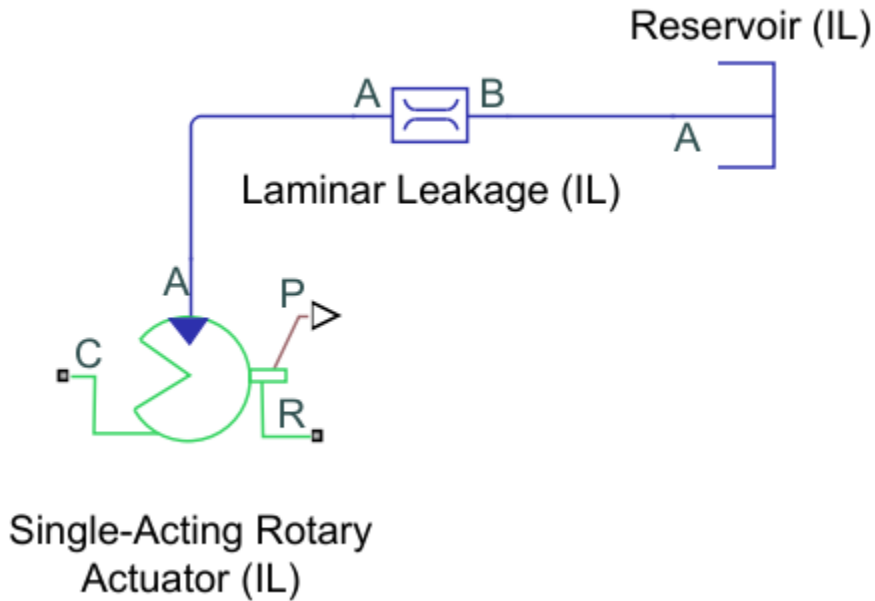
- Ideal Rotational Motion Sensor
- Rotational Hard Stop
- Rotational Mechanical Converter (IL)



## Underlying Block Components

### Leakage

Laminar leakage is not accounted for in the Single-Acting Rotary Actuator (IL) block. To include leakage in your simulation, set the **Cross-sectional geometry** parameter to **Custom** and connect port **A** to port **A** of the Laminar Leakage (IL) block. Connect port **B** of the Laminar Leakage (IL) block to a Reservoir (IL) block.



### Adding Leakage to the Simulation

#### Ports

##### Conserving

##### **A – Liquid port**

isothermal liquid

Isothermal liquid conserving port associated with the actuator.

##### **R – Actuator**

mechanical translational

Mechanical rotational conserving port associated with the shaft angular velocity and torque.

##### **C – Casing**

mechanical translational

Mechanical rotational conserving port associated with the actuator casing.

##### Input

##### **q – Shaft angle**

physical signal

Shaft angle, received as a physical signal from a Simscape Multibody block.

##### Dependencies

To expose this port, set **Shaft rotation from chamber A** to Provide input signal from Multibody joint.

## Output

### **q – Shaft angle**

physical signal

Shaft angle, reported as a physical signal.

### Dependencies

To expose this port, set **Shaft rotation from chamber A** to Calculate from angular velocity of port R relative to port C.

## Parameters

### Actuator

#### **Mechanical orientation – Piston displacement direction**

Pressure at A causes positive displacement of R relative to C (default) | Pressure at A causes negative displacement of R relative to C

Sets the piston displacement direction. When you set this parameter to:

- Pressure at A causes positive displacement of R relative to C the piston displacement is positive when the volume of liquid at port A is expanding. This corresponds to rod extension.
- Pressure at A causes negative displacement of R relative to C the piston displacement is negative when the volume of liquid at port A is expanding. This corresponds to rod contraction.

#### **Volume displacement – Volume displacement**

$1e-4 \text{ m}^3/\text{rad}$  (default) | positive scalar

Effective displacement of the actuator.

#### **Stroke – Angle**

$5.0 \text{ rad}$  (default) | positive scalar

Shaft maximum travel between stops.

#### **Dead volume – Fluid volume**

$1e-5 \text{ m}^3$  (default) | positive scalar

Volume of liquid when the piston displacement is 0. This is the liquid volume when the piston is up against the actuator end cap.

#### **Environment pressure specification – Pressure reference source**

Atmospheric pressure (default) | Specified pressure

Choice of environment pressure. Options include Atmospheric pressure and Specified pressure.

#### **Environment pressure – User-defined pressure reference**

$0.101325 \text{ MPa}$  (default)

Pressure outside the actuator casing. This pressure acts against the pressures inside the actuator chambers. A value of zero corresponds to a vacuum.

**Dependencies**

To enable this parameter, set **Environment pressure specification** to Specified pressure.

**Hard Stop****Hard stop stiffness coefficient – Stiffness coefficient**

1e6 N\*m/rad (default) | positive scalar

Specifies the elastic property of colliding bodies for the Rotational Hard Stop block. The greater the value of the parameter, the more rigid the impact between the piston and the stop becomes. Lower values make contact softer and generally improve convergence and computational efficiency.

**Hard stop damping coefficient – Damping coefficient**

150 N\*m(rad/s) (default) | positive scalar

Specifies the dissipating property of colliding bodies for the Rotational Hard Stop block. At zero damping, the impact is elastic. The greater the value of the parameter, the greater the energy dissipation during piston-stop interaction. Damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. Set this parameter to a nonzero value to improve the efficiency and convergence of your simulation.

**Hard stop model – Model choice for force on piston at full extension or retraction**

Stiffness and damping applied smoothly through transition region, damped rebound (default) | Full stiffness and damping applied at bounds, undamped rebound | Full stiffness and damping applied at bounds, damped rebound

Model choice for the force on the piston at full extension or full retraction. See the Rotational Hard Stop block for more information.

**Transition region – Transition region**

0.001 rad (default) | positive scalar

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value of this parameter. The contact force is at its full value when the distance to the hard stop is zero.

**Initial Conditions****Shaft rotation from chamber A – Method for determining shaft angle**

Calculate from angular velocity of port R relative to port C (default) | Provide input signal from Multibody joint

Method for determining the shaft angle. The block can receive the angle from a Multibody block when set to Provide input signal from Multibody joint, or calculates the angle internally, which is reported at port **q**.

**Initial shaft rotation – Initial rotation**

0 rad (default) | scalar

The position of the actuator at the beginning of simulation. This value falls between 0 and the value of the **Stroke** in the positive orientation, and 0 and the negative value of the **Stroke** in the negative orientation.

### Dependencies

To enable this parameter, set **Shaft rotation from chamber A** to Calculate from angular velocity of port R relative to port C.

### Fluid dynamic compressibility – Fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

### Initial liquid pressure – Liquid pressure

0.101325 MPa (default) | positive scalar

Pressure in actuator chamber A at the start of simulation.

### Dependencies

To enable this parameter, set **Fluid dynamic compressibility** to On.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Rotating Single-Acting Actuator (IL) | Single-Acting Actuator (IL) | Double-Acting Rotary Actuator (IL) | Double-Acting Actuator (IL)

## Topics

“Connecting Simscape Networks to Simscape Multibody Joints”

# Single-Acting Rotary Actuator

Single-acting hydraulic rotary actuator



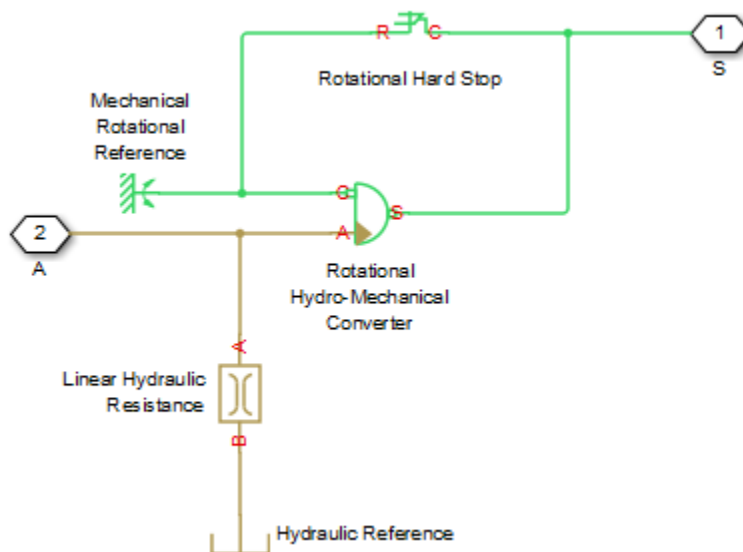
## Library

Hydraulic Cylinders

## Description

The Single-Acting Rotary Actuator block models a single-acting hydraulic rotary actuator, which directly converts hydraulic energy into mechanical rotational energy without employing intermediary transmissions such as rack-and-pinion, sliding spline, chain, and so on. Single-acting actuators generate torque and motion in a single direction only. Use an external device, such as a spring or another opposite installed actuator, to move the shaft in the opposite direction.

The model of the actuator is built of Simscape Foundation library blocks. The schematic diagram of the model is shown below.



The blocks in the diagram perform the following functions:

Rotational Hydro-Mechanical Converter	Converts hydraulic energy into mechanical rotational energy and vice versa, while accounting for fluid compressibility.
Rotational Hard Stop	Imposes limits on shaft rotation.

Linear Hydraulic Resistance	Accounts for leakages.
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Connection A is a hydraulic conserving port corresponding to the actuator chamber. Connection S is a mechanical rotational conserving port associated with the actuator shaft.

The block directionality is adjustable and can be controlled with the **Actuator orientation** parameter.

## Basic Assumptions and Limitations

No loading, such as inertia, friction, spring, and so on, is taken into account. If necessary, you can easily add them by connecting an appropriate building block to port S.

## Parameters

### Actuator displacement

Effective displacement of the actuator. The default value is  $4.5 \times 10^{-5} \text{ m}^3/\text{rad}$ .

### Shaft stroke

Shaft maximum travel between stops. The default value is  $5.1 \text{ rad}$ .

### Shaft initial angle

The position of the shaft at the beginning of simulation. You can set the shaft position to any angle within its stroke. The default value is  $0$ , which corresponds to the shaft position at the very beginning of the stroke.

### Dead volume

Fluid volume that remains in the chamber when the shaft is positioned at the very beginning of the stroke. The default value is  $1 \times 10^{-4} \text{ m}^3$ .

### Leak coefficient

Leak coefficient for the Linear Hydraulic Resistance block. The default value is  $1 \times 10^{-14} \text{ (m}^3/\text{s)/Pa}$ .

### Specific heat ratio

Gas-specific heat ratio for the Hydraulic Piston Chamber block. The default value is  $1.4$ .

### Contact stiffness

Specifies the elastic property of colliding bodies for the Rotational Hard Stop block. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is  $1 \times 10^6 \text{ N}\cdot\text{m}/\text{rad}$ .

### Contact damping

Specifies dissipating property of colliding bodies for the Rotational Hard Stop block. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, MathWorks recommends that you assign a nonzero value to this parameter. The default value is  $150 \text{ N}\cdot\text{m}/(\text{rad}/\text{s})$ .

### Hard stop model

Modeling approach for hard stops. Options include:

- **Stiffness and damping applied smoothly through transition region (default)** — Scale the magnitude of the contact force from zero to its full value over a specified transition length. The scaling is polynomial in nature. The polynomial scaling function is numerically smooth and it produces no zero crossings of any kind.
- **Full stiffness and damping applied at bounds, undamped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during penetration and a spring force—without a damping component—during rebound. No smoothing is applied.
- **Full stiffness and damping applied at bounds, damped rebound** — Apply the full value of the calculated contact force when the hard-stop location is breached. The contact force is a mix of spring and damping forces during both penetration and rebound. No smoothing is applied. This is the hard-stop model used in previous releases.

### **Transition region**

Distance below which scaling is applied to the hard-stop force. The contact force is zero when the distance to the hard stop is equal to the value specified here. It is at its full value when the distance to the hard stop is zero. The default value is 1 mm.

### **Actuator orientation**

Specifies actuator orientation with respect to the globally assigned positive direction. The actuator can be installed in two different ways, depending upon whether it generates torque in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A generates torque in the negative direction, set the parameter to **Acts in negative direction**. The default value is **Acts in positive direction**.

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Actuator orientation**

All other block parameters are available for modification.

### **Global Parameters**

Parameter determined by the type of working fluid:

- **Fluid bulk modulus**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

### **Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the actuator inlet.

S

Mechanical rotational conserving port associated with the actuator shaft.



## **Version History**

**Introduced in R2007a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Linear Hydraulic Resistance | Rotational Hard Stop | Rotational Hydro-Mechanical Converter

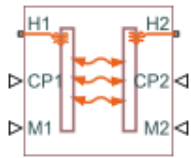
## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Specific Dissipation Heat Transfer

Simple heat transfer model between two general fluids

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers / Fundamental Components



## Description

The Specific Dissipation Heat Transfer block models the heat transfer between two fluids given only minimal knowledge of component parameters. The fluids are controlled by physical signals, with these providing the entrance mass flow rate and isobaric specific heat for each. Thermal ports set the entrance temperatures of the fluids.

The rate of heat transfer is calculated from the specific dissipation, a parameter specified in tabulated form as a function of the entrance mass flow rates. The specific dissipation quantifies the amount of heat exchanged between the fluids per unit of time when the entrance temperatures differ by one degree.

Pressure losses and other aspects of flow mechanics are ignored. To capture such effects, use the heat exchanger interface blocks provided in the same library. Combine heat transfer and heat exchanger blocks to model a custom heat exchanger. See the composite block diagrams of the heat exchanger blocks for examples.

## Heat Transfer Rate

Heat flows from the warmer fluid to the cooler fluid, at a rate proportional to the difference between the fluid entrance temperatures. The heat flow rate is positive if fluid 1 enters at a higher temperature than fluid 2—and therefore if heat flows from fluid 1 to fluid 2:

$$Q = SD(T_{1,in} - T_{2,in}),$$

where  $T_{*,in}$  are the fluid entrance temperatures, determined by the conditions at thermal port **H1** for fluid 1 and **H2** for fluid 2.  $SD$  is the specific dissipation obtained from the specified tabulated data at the given mass flow rates:

$$SD = SD(\dot{m}_1, \dot{m}_2),$$

where  $\dot{m}$  are the entrance mass flow rates, specified through physical signal port **M1** for fluid 1 and **M2** for fluid 2. The specific dissipation can be calculated for a set of entrance mass flow rates ( $\dot{m}_1$ ,  $\dot{m}_2$ ) given the experimental values of the heat transfer rate and the corresponding entrance temperature difference:

$$SD = \frac{Q}{T_{1,in} - T_{2,in}}.$$

### Maximum Heat Transfer Rate

The heat transfer rate is constrained so that the specific dissipation used in the calculations can never exceed the maximum value:

$$SD_{\max} = \min(C_1, C_2),$$

where  $C_*$  are the thermal capacity rates of the controlled fluids, each defined as:

$$C_* = \dot{m}_* c_{p,*},$$

with  $c_{p,*}$  denoting the isobaric specific heat of the fluid, specified through physical signal port **CP1** for fluid 1 and **CP2** for fluid 2. The constraint on the maximum heat transfer rate is implemented in the form of a piecewise function:

$$Q = \begin{cases} SD_{\max}(T_{1,in} - T_{2,in}), & \text{if } SD > SD_{\max} \\ SD(T_{1,in} - T_{2,in}), & \text{otherwise} \end{cases},$$

A warning is issued whenever the heat flow rate exceeds the maximum value,  $SD_{\max}(T_{1,in} - T_{2,in})$ , if the **Check if violating maximum specific dissipation** block parameter is set to **Warning**.

## Ports

### Input

#### CP1 — Isobaric specific heat of controlled fluid 1

physical signal

Isobaric specific heat of controlled fluid 1.

#### CP2 — Isobaric specific heat of controlled fluid 2

physical signal

Isobaric specific heat of controlled fluid 2.

#### M1 — Entrance mass flow rate of controlled fluid 1

physical signal

Entrance mass flow rate of controlled fluid 1. Positive values indicate flow into the heat exchanger. Negative values indicate flow out of the heat exchanger.

#### M2 — Entrance mass flow rate of controlled fluid 2

physical signal

Entrance mass flow rate of controlled fluid 2. Positive values indicate flow into the heat exchanger. Negative values indicate flow out of the heat exchanger.

### Conserving

#### H1 — Entrance temperature of controlled fluid 1

thermal

Entrance temperature of controlled fluid 1.

**H2 — Entrance temperature of controlled fluid 2**

thermal

Entrance temperature of controlled fluid 2.

**Parameters****Thermal Liquid mass flow rate vector, mdot1 — Entrance mass flow rate at which to specify specific-dissipation data**

[.3, .5, .6, .7, 1, 1.4, 1.9, 2.3] kg/s (default) |  $M$ -element array with units of mass/time

Array of mass flow rates at the inlet for controlled fluid 1. Each value corresponds to a row in the specific dissipation lookup table. Positive values indicate flow into the heat exchanger and negative values indicate flow out of the heat exchanger.

**Controlled fluid mass flow rate vector, mdot2 — Entrance mass flow rate at which to specify specific-dissipation data**

[.3, .5, 1, 1.3, 1.7, 2, 2.6, 3.3] kg/s (default) |  $N$ -element array with units of mass/time

Array of mass flow rates at the inlet for controlled fluid 2. Each value corresponds to a row in the specific dissipation lookup table. Positive values indicate flow into the heat exchanger and negative values indicate flow out of the heat exchanger.

**Specific dissipation table, SD(mdot1, mdot2) — Specific dissipation values corresponding to specified mass flow rates**

8-by-8 matrix with units of kW/K (default) |  $M$ -by- $N$  matrix with units of power/temperature

Matrix of specific dissipation values corresponding to the specified mass flow rate arrays for controlled fluids 1 and 2. The block uses the tabulated data to calculate the heat transfer at the simulated operating conditions.

**Mass flow rate threshold for flow reversal — Mass flow rate below which to smooth numerical data**

1e-3 kg/s (default) | scalar with units of mass/time

Mass flow rate below which to initiate a smooth flow reversal to prevent discontinuities in the simulation data.

**Check if violating maximum specific dissipation — Option to warn if the specific dissipation exceeds the maximum allowed value**

Warning (default) | None

Option to warn if the specific dissipation exceeds the maximum value described in the block description.

**Version History**

Introduced in R2017b

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

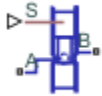
### **See Also**

Simple Heat Exchanger Interface (G) | Simple Heat Exchanger Interface (TL)

## Spool Orifice (IL)

Variable-area spool orifice in an isothermal system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Orifices



### Description

The Spool Orifice (IL) block models a variable-area orifice between a spool and a sleeve with holes. The sleeve holes can be either a series of round or rectangular holes. The flow rate is based on the total opening area between the sleeve, holes, and spool, which extends or retracts according to the signal received at port **S**. Multiple Spool Orifice (IL) blocks can be connected for multiple sets of holes along a spool-sleeve pair.

If the spool displacement in your system is supplied by an external source or custom block and you would like the axial flow force to be transmitted to the system, you can use the Spool Orifice Flow Force (IL) block, which applies the same equations for force as the Spool Orifice (IL) block.

### Flow Force

The force on the spool is calculated as:

$$F = \frac{-\dot{m}_A^2}{\rho A} \cos(\alpha) \varepsilon,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\rho$  is the fluid density.
- $A$  is the orifice open area, which is determined by the spool position and orifice parameterization.
- $\alpha$  is the jet angle, which is calculated from an approximation of the Von Mises formula:

$$\alpha_{jet} = 0.3663 + 0.8373 \left( 1 - e^{\frac{-h}{1.848c}} \right),$$

where  $c$  is the **Radial clearance**, and  $h$  is the orifice opening.

- $\varepsilon$  is the **Orifice orientation**, which indicates orifice opening that is associated with a positive or negative signal at **S**.

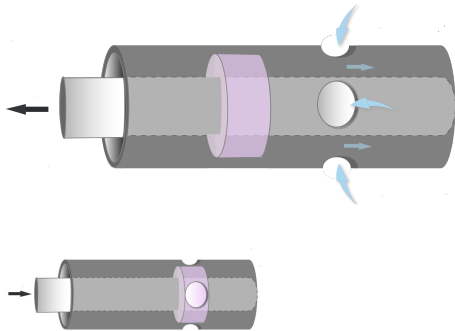
### Orifice Opening Area

For variable orifices, setting **Orifice orientation** to **Positive** spool displacement opens the orifice indicates that the orifice opens when the control member extends, while **Negative** spool displacement opens the orifice indicates that the orifice opens when the control member retracts.

The **Leakage area**,  $A_{leak}$ , is considered a small area open to flow when the orifice is closed, which maintains numerical continuity. Additionally, a nonzero **Smoothing factor** can provide increased numerical stability when the orifice is in near-closed or near-open position.

### Round Holes

Setting **Orifice parameterization** to Round holes evenly distributes a user-defined number of holes along the sleeve perimeter with the equal diameters and centers aligned in the same plane.



The open area is calculated as:

$$A_{orifice} = n_0 \frac{d_0^2}{8} (\theta - \sin(\theta)) + A_{leak}.$$

The orifice opening angle,  $\theta$ , is set by the control signal at **S**:

$$\theta = 2 \cos^{-1} \left( \theta - \frac{2\Delta S}{d_0} \right),$$

where:

- $n_0$  is the number of holes.
- $d_0$  is the diameter of the holes.
- $A_{leak}$  is  $A_{leak} = cd_0 n_0$ .
- $\Delta S$  is the control member travel distance,  $\varepsilon(S - S_{min})$ , where  $S_{min}$  is the **Control member position at closed orifice**.

The maximum open area is:

$$A_{max} = \frac{\pi}{4} d_0^2 n_0 + A_{leak}.$$

### Rectangular Slot

Setting **Orifice parameterization** to Rectangular slot models one rectangular slot in the tube sleeve.



For an orifice with a slot in a rectangular sleeve, the open area is

$$A_{orifice} = w\Delta S + A_{leak},$$

where  $w$  is the orifice width.

The maximum opening distance between the sleeve and case is:

$$A_{max} = w\Delta S_{max} + A_{leak}.$$

where  $\Delta S_{max}$  is the slot orifice **Spool travel between closed and open orifice** distance.

At the minimum orifice opening area, the leakage area is:

$$A_{leak} = cw.$$

### Numerically-Smoothed Displacement

At the extremes of the orifice opening range, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. The block applies a smoothing function to every calculated displacement, but primarily influences the simulation at the extremes of this range.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the orifice opening between  $\theta$  and  $\Delta S_{max}$  where  $\Delta S_{max}$  is the:

- Value of the **Diameter of round holes** parameter, when **Orifice parameterization** is set to Round holes.
- Value of the **Spool travel between closed and open orifice** parameter, when **Orifice parameterization** is set to Rectangular slot.

For more information, see “Numerical Smoothing”.

### The Mass Flow Rate Equation

The flow through a spool orifice is calculated by the pressure-flow rate equation:

$$\dot{m} = \frac{C_d A_{orifice} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left(1 - \left(\frac{A_{orifice}}{A}\right)^2\right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.
- $A_{orifice}$  is the orifice open area, unless:
  - The opening is larger than or equal to the area at the **Spool travel between closed and open orifice** distance. The orifice area is then  $A_{max}$ .
  - The orifice opening is less than or equal to the minimum opening distance. The orifice area is then  $A_{leak}$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , which is the point of transition between laminar and turbulent flow in the fluid:



$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{orifice}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

*Pressure loss* describes the reduction of pressure in the orifice due to a decrease in area.  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left( \frac{A_{orifice}}{A_{port}} \right)^2 (1 - C_d^2)} - C_d \frac{A_{orifice}}{A_{port}}}{\sqrt{1 - \left( \frac{A_{orifice}}{A_{port}} \right)^2 (1 - C_d^2)} + C_d \frac{A_{orifice}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the orifice due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the orifice.

#### B — Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the orifice.

### Input

#### S — Control member displacement, m

physical signal

Control member displacement for a variable-area orifice, in m.

### Output

#### F — Flow force, N

physical signal

Axial flow force, in N.

## Parameters

### Orifice parameterization — Type of orifice

Round holes (default) | Rectangular slot

Hole geometry in the sleeve. The round holes are spaced evenly about the cross-sectional circumference. There is only one hole in the Rectangular slot setting.

### Diameter of round holes — Diameter of round holes

5e-3 m (default) | positive scalar

Diameter of all holes on the sleeve.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Round holes.

**Number of round holes — Number of round holes**

6 (default) | positive integer

Number of holes along the sleeve circumference.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Round holes.

**Orifice width — Rectangular slot width**

0.01 m (default) | positive scalar

Rectangular slot width.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Rectangular slot.

**Spool travel between closed and open orifice — Control member maximum stroke**

5e-3 m (default) | positive scalar

Maximum distance of the control member travel. This value provides an upper limit to calculations so that simulations do not return unphysical values.

**Dependencies**

To enable this parameter, set **Orifice parametrization** to Rectangular slot.

**Flow force output — Whether to model axial hydraulic force on the spool**

Off (default) | On

Whether to model the axial hydraulic force on the spool. When this parameter is set to On, port **F** is enabled and outputs the axial force as a physical signal, in N.

**Radial clearance — Spool-sleeve clearance**

1e-5 m (default) | positive scalar

Radial distance between the spool and the sleeve.

**Dependencies**

To enable this parameter, set **Flow force effect** to On.

**Leakage area — Gap area when valve is in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Spool position at closed orifice — Spool offset**

0 (default) | scalar

Spool offset when the orifice is fully open. A positive, nonzero value indicates a partially closed orifice. A negative, nonzero value indicates an overlapped orifice that remains open for an initial displacement set by the physical signal at port **S**.

### **Cross-sectional area at ports A and B — Orifice area at conserving ports**

`inf m^2` (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. This area is used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

### **Opening orientation — Direction of changing orifice area**

`Positive spool displacement opens the orifice` (default) | `Negative spool displacement opens the orifice`

Direction of the area change for variable orifices. A positive opening orientation indicates an increase in the orifice opening. A negative orientation indicates a decrease in the orifice opening. The magnitude is always positive.

### **Discharge coefficient — Discharge coefficient**

`0.64` (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

### **Critical Reynolds number — Upper Reynolds number limit for laminar flow**

`150` (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

### **Smoothing factor — Numerical smoothing factor**

`0.01` (default) | positive scalar

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

### **Pressure recovery — Whether to account for pressure increase in area expansions**

`Off` (default) | `On`

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

## **Version History**

Introduced in R2020a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

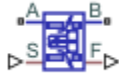
## **See Also**

Spool Orifice Flow Force (IL) | Variable Overlapping Orifice (IL) | Annular Leakage (IL) | Orifice (IL)

## Spool Orifice Flow Force (IL)

Axial fluid force on spool orifice in an isothermal liquid system

**Library:** Simscape / Fluids / Valve Actuators & Forces



### Description

The Spool Orifice Flow Force (IL) block models the hydraulic axial force on a spool orifice. It receives the spool position as a physical signal at port **S**. You can also model the flow through a spool orifice with round or rectangular holes. A positive force acts to close the orifice.

If you would like to model the spool and axial force in one block, use the Spool Orifice (IL) block. The axial force is output as a physical signal at port **F**.

### Flow Force

The force on the spool is calculated as:

$$F = \frac{-\dot{m}_A^2}{\rho A} \cos(\alpha) \varepsilon,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\rho$  is the fluid density.
- $A$  is the orifice open area, which is determined by the spool position and orifice parameterization.
- $\alpha$  is the jet angle, which is calculated from an approximation of the Von Mises formula:

$$\alpha_{jet} = 0.3663 + 0.8373 \left( 1 - e^{\frac{-h}{1.848c}} \right),$$

where  $c$  is the **Radial clearance** and  $h$  is the orifice opening.

- $\varepsilon$  is the opening orientation, which indicates orifice opening that is associated with a positive or negative signal at **S**.

### Opening Area

The orifice opening is based on the open area created by the displaced spool:

$$\Delta S = (S - S_{\min}) \varepsilon,$$

where:

- $S_{\min}$  is the **Spool position at closed orifice**.
- $S$  is the displacement signal at port **S**.

If  $\Delta s$  falls below 0, the orifice leakage area is used. If  $\Delta S$  is greater than the **Spool travel between closed and open orifice**, the maximum orifice area is used.

### Round Holes

Setting **Orifice geometry** to Round holes evenly distributes a user-defined number of holes along the sleeve perimeter that have equal diameters and centers aligned in the same plane.

The open area is calculated as:

$$A_{orifice} = n_0 \frac{d_0^2}{8} \left( \theta - \sin\left(\frac{\theta}{2}\right) \right) + A_{leak},$$

where:

- $n_0$  is the number of holes.
- $d_0$  is the diameter of the holes.
- $\theta$  is the orifice opening angle:

$$\theta = \cos^{-1}\left(1 - 2\frac{\Delta S}{d_0}\right).$$

If  $\theta$  is greater than  $2\pi$ ,  $\theta$  remains at  $2\pi$ .

- $A_{leak}$  is the **Leakage area**.

The maximum open area is:

$$A_{max} = \frac{\pi}{4} d_0^2 n_0 + A_{leak}.$$

### Rectangular Slot

Setting **Orifice geometry** to Rectangular slot models one rectangular slot in the tube sleeve.

For an orifice with a slot in a rectangular sleeve, the open area is

$$A_{orifice} = w\Delta S + A_{leak},$$

where  $w$  is the orifice width.

The maximum opening distance between the sleeve and case is:

$$A_{max} = w\Delta S_{max} + A_{leak}.$$

where  $\Delta S_{max}$  is the **Spool travel between closed and open orifice**.

### Numerically-Smoothed Displacement

At the extremes of the orifice opening range, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. The block applies a smoothing function to every calculated displacement, but primarily influences the simulation at the extremes of this range.

If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the orifice opening between  $\theta$  and  $\Delta S_{max}$  where  $\Delta S_{max}$  is the:

- Value of the **Diameter of round holes** parameter, when **Orifice parameterization** is set to Round holes.
- Value of the **Spool travel between closed and open orifice** parameter, when **Orifice parameterization** is set to Rectangular slot.

For more information, see “Numerical Smoothing”.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Liquid entry or exit port to the block.

#### **B – Liquid port**

isothermal liquid

Liquid entry or exit port to the block.

### Input

#### **S – Control member displacement, m**

physical signal

Spool displacement in m, specified as a physical signal.

### Output

#### **F – Flow force, N**

physical signal

Axial flow force in N, specified as a physical signal.

## Parameters

#### **Orifice geometry – Type of orifice**

Round holes (default) | Rectangular slot

Whether the modeled spool has round holes or a rectangular slot in the sleeve.

#### **Diameter of round holes – Diameter of round holes**

5e-3 m (default) | positive scalar

Diameter of all holes on the sleeve.

### Dependencies

To enable this parameter, set **Orifice geometry** to Round holes.

#### **Number of round holes – Number of round holes**

6 (default) | positive integer

Number of holes along the sleeve circumference.

**Dependencies**

To enable this parameter, set **Orifice geometry** to Round holes.

**Orifice width – Rectangular slot width**

0.01 m (default) | positive scalar

Rectangular slot width.

**Dependencies**

To enable this parameter, set **Orifice geometry** to Rectangular slot.

**Spool travel between closed and open orifice – Maximum spool stroke**

1 m (default) | positive scalar

Maximum orifice opening, including the **Spool position at maximum orifice area**.

**Dependencies**

To enable this parameter, set **Orifice geometry** to Rectangular slot.

**Radial clearance – Spool-sleeve clearance**

1e-5 m (default) | positive scalar

Radial distance between the spool and the sleeve.

**Spool position at closed orifice – Initial spool offset**

0 m (default) | scalar

Initial offset if the spool is extended or retracted in its neutral position.

**Opening orientation – Direction of changing orifice area**

Positive spool displacement opens orifice (default) | Negative spool displacement closes orifice

Direction of member movement that opens the orifice. A positive orientation indicates that positive control member displacement increases the orifice opening. A negative orientation indicates that negative control member displacement increases the orifice opening. The magnitude is always positive.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Version History**

Introduced in R2020a

**References**

[1] Manring, N. *Hydraulic Control Systems*. John Wiley & Sons, 2005.

[2] Merritt, H. *Hydraulic Control Systems*. Wiley, 1967.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

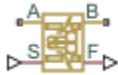
### **See Also**

Spool Orifice (IL) | Variable Overlapping Orifice (IL)



# Spool Orifice Hydraulic Force

Axial hydraulic force exerted on spool



## Library

Valve Forces

### Description

The Spool Orifice Hydraulic Force block simulates the steady-state axial hydraulic force exerted on the spool by fluid flowing through the orifice. The spool is assumed to be sharp-edged. You have two parameterization options:

- A rectangular slot, to be used with the Orifice with Variable Area Slot block
- A round hole, or a set of round holes, to be used with the Orifice with Variable Area Round Holes block

The width of the slot, or the diameter of the holes, must be considerably larger than the radial clearance between the spool and the sleeve. Connect the Spool Orifice Hydraulic Force block in series with the respective orifice block to monitor the flow rate.

The force is simulated according to the following equations:

$$F = \rho \frac{q^2}{A} \cos\theta \cdot or$$

$$\theta = 0.3663 + 0.8373(1 - \exp(-x/1.848))$$

$$x = x_0 + s \cdot or$$

For rectangular slot,

$$A = \begin{cases} b \cdot \sqrt{x^2 + \delta^2} & \text{for } x > 0 \\ b \cdot \delta & \text{for } x \leq 0 \end{cases}$$

For round holes,

$$A = \begin{cases} A_{\min} + Z \frac{d^2}{8} (\alpha - \sin\alpha) & \text{for } d \geq x \geq 0 \\ A_{\min} & \text{for } x < 0 \\ A_{\min} + A_{\max} & \text{for } x > d \end{cases}$$

$$\alpha = 2 \cdot \arccos\left(1 - 2\frac{x}{d}\right)$$

$$A_{\min} = Z \cdot d \cdot \delta$$

$$A_{\max} = \pi d^2 / 4$$

where

$F$	Axial hydraulic force
$q$	Flow rate through the orifice
$\rho$	Fluid density
$A$	Orifice area
$\Theta$	Jet angle (rad)
$x_0$	Orifice initial opening
$s$	Spool displacement
$b$	Orifice width, for rectangular slot
$D$	Orifice diameter, for round holes
$Z$	Number of round holes
$\delta$	Radial clearance
$or$	Orientation parameter with respect to the globally assigned positive direction. If the orifice is opened while the spool is shifted in positive direction, $or$ equals 1. If the orifice is opened while the spool is shifted in negative direction, $or$ equals -1.

Connections A and B are hydraulic conserving ports that should be connected in series with the orifice block to monitor the flow rate. Connection S is a physical signal port that provides the spool displacement. Connection F is a physical signal port that outputs the hydraulic axial force value. This port should be connected to the control port of an Ideal Force Source block. The force computed in the block always acts to close the orifice.

## Basic Assumptions and Limitations

- The transient effects are assumed to be negligible.
- The jet angle approximation is based on the Richard von Mises equation.
- The jet angle variation with the orifice opening is identical for the rectangular slot and the round holes orifices.
- The block can be used with orifices whose width or diameter is considerably larger than the axial opening.

## Parameters

### Orifice type

Select the type of orifice:

- **Rectangular slot** — Orifice created by the sharp-edged spool and a rectangular slot in the sleeve. This is the default.
- **Round holes** — Orifice created by the sharp-edged spool and a set of round holes evenly distributed along the sleeve perimeter.

**Orifice width**

Orifice width. The parameter must be greater than zero. The default value is 0.01 m. The parameter is used if **Orifice type** is set to Rectangular slot.

**Diameter of round holes**

Orifice diameter. If multiple orifices are used, all of them must be of the same diameter, identically aligned with respect to the spool edge, and spaced evenly among the sleeve perimeter. The parameter must be greater than zero. The default value is 0.005 m. The parameter is used if **Orifice type** is set to Round holes.

**Number of round holes**

Number of round holes in the sleeve. The parameter must be greater than zero. The default value is 4. The parameter is used if **Orifice type** is set to Round holes.

**Radial clearance**

The radial clearance between the spool and the sleeve. The default value is 1e-5 m.

**Initial opening**

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The default value is 0.

**Orifice orientation**

The parameter is introduced to specify the effect of the force on the orifice opening. The parameter can be set to one of two options: **Opens in positive direction** or **Opens in negative direction**. The value **Opens in positive direction** specifies an orifice that opens when the spool moves in the globally assigned positive direction. The default value is **Opens in positive direction**.

**Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Orifice type**
- **Orifice orientation**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Orifice type** parameter at the time the model entered Restricted mode.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with an orifice inlet.

B

Hydraulic conserving port associated with an orifice outlet.

S

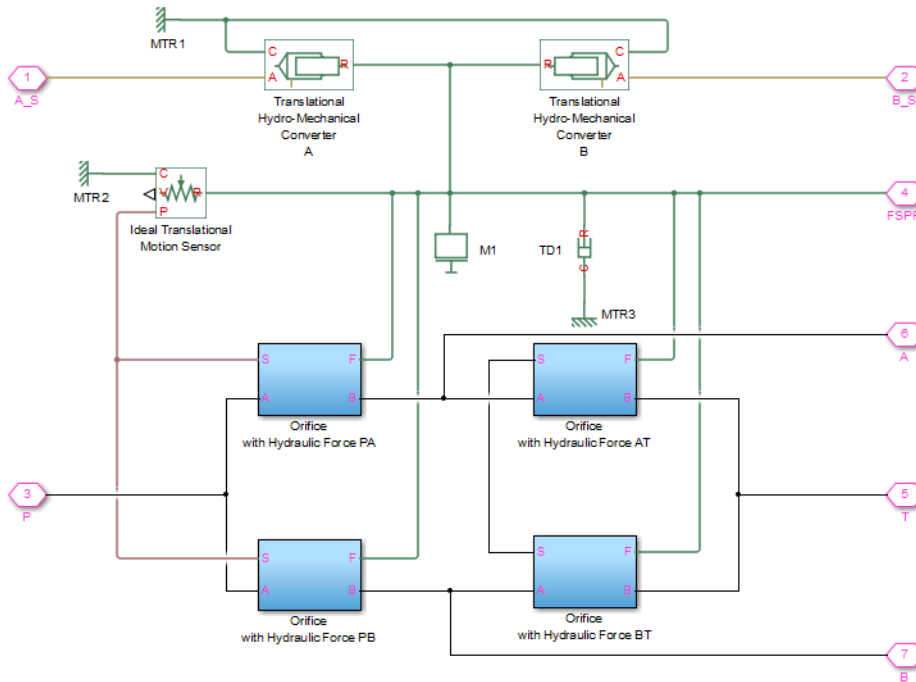
Physical signal port that provides the spool displacement.

F

Physical signal port that outputs hydraulic axial force.

## Examples

The following example shows a model of a 4-way, 3-position, hydraulically-operated directional valve where the hydraulic axial forces acting on the spool are being taken into consideration.

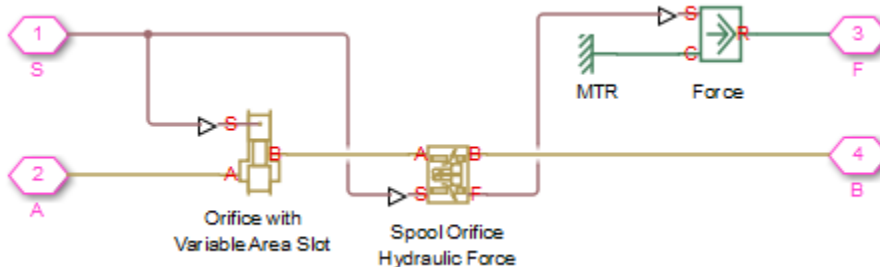


The spool (mass M1, viscous friction TD1) is shifted by the servo-actuator simulated by two Translational Hydro-Mechanical Converter blocks. Connections A\_S and B\_S are hydraulic ports for applying pilot control pressure.

Four variable orifices are represented by subsystems:

- Orifice with Hydraulic Force PA
- Orifice with Hydraulic Force PB
- Orifice with Hydraulic Force AT
- Orifice with Hydraulic Force BT

The structure of a subsystem is shown in the following illustration.



It consists of an Orifice with Variable Area Slot block, which simulates hydraulic properties of the orifice, connected in series with a Spool Orifice Hydraulic Force block. The force value computed in the block is exported through its port F and passed to the Force block.

The forces on all four orifices (F\_PA, F\_PB, F\_AT, F\_BT) are applied to the valve spool as it is shown in the first schematic.

For more details and for parameter settings, see the “Servo-Valve Controlling Hydraulic Actuator” example.

## **Version History**

**Introduced in R2007a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Valve Hydraulic Force

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Spring-Loaded Accumulator (IL)

Accumulator with a spring used for energy storage in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Tanks & Accumulators

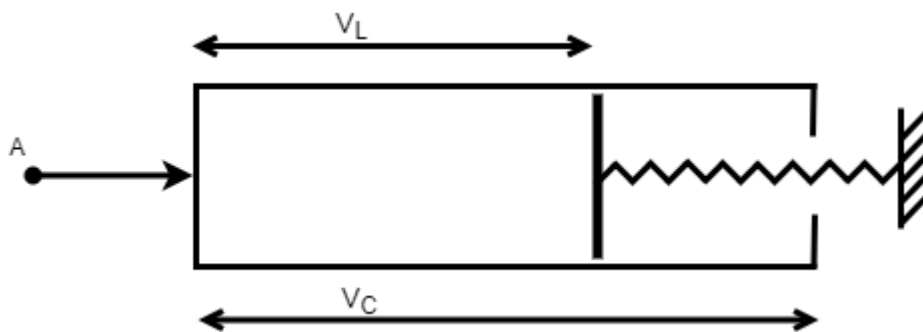


### Description

This block models a spring-charged accumulator in an isothermal liquid network. The accumulator consists of a preloaded spring and a liquid chamber.

As the liquid pressure at the accumulator inlet becomes greater than the preload pressure, liquid enters the accumulator and compresses the spring. A decrease in the liquid pressure causes the spring to decompress and discharge stored liquid into the system. The separator motion is restricted by a hard stop when the liquid volume is zero and when the liquid volume is at the liquid chamber capacity.

The inlet liquid resistance and spring properties, such as the spring inertia and damping, are not modeled. The spring pressure is assumed to be linear with respect to the liquid volume. The flow rate is positive if liquid flows into the accumulator.



This diagram represents a spring-loaded accumulator.

$V_L$	Volume of the liquid in the accumulator.
$V_C$	Liquid chamber capacity
$p_{\max}$	Pressure at full capacity
$p_I$	Liquid pressure in the liquid chamber, which is equal to the pressure at the accumulator inlet.
$p_{HS}$	Hard-stop contact pressure.
$K_{stiff}$	Hard-stop stiffness coefficient.
$K_{spring}$	Spring gain.
$\dot{m}_A$	Mass flow rate of liquid coming into port A.

$\rho_I$	Density of the liquid in the liquid chamber.
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### Conservation of Mass

Conservation of mass is represented by the following equation.

$$\begin{cases} \dot{p}_I \frac{d\rho_I}{dp_I} V_L + \rho_I \dot{V}_L = \dot{m}_A, & \text{compressibility on} \\ \rho_I \dot{V}_L = \dot{m}_A, & \text{compressibility off} \end{cases}$$

where

$$\dot{V}_L = \begin{cases} \frac{\dot{p}_I}{K_{spring}}, & \text{if } 0 < V_L < V_C \\ \frac{\dot{p}_I}{K_{spring} + K_{stiff}}, & \text{else} \end{cases}$$

### Conservation of Momentum

Conservation of momentum is represented by the following equation.

$$p_I = p_{spring} + p_{HS}$$

where

$$\begin{aligned} p_{spring} &= p_{pr} + K_{spring} V_L \\ p_{HS} &= \begin{cases} (V_L - V_C) K_{stiff}, & \text{if } V_L \geq V_C \\ V_L K_{stiff}, & \text{if } V_L \leq 0 \\ 0, & \text{else} \end{cases} \end{aligned}$$

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Conserving

#### A — Hydraulic conserving port

hydraulic conserving

Hydraulic conserving port associated with the accumulator inlet. The flow rate is positive if liquid flows into the accumulator.

## Parameters

### Liquid capacity — Liquid capacity

8e-3 m<sup>3</sup> (default) | positive scalar

Amount of liquid that the accumulator can hold.

### Preload pressure — Spring pressure

1.01325 MPa (default) | positive scalar

Spring pressure when the liquid chamber is empty.

### Pressure at full capacity — Spring pressure

3.01325 MPa (default) | positive scalar

Spring pressure when the liquid chamber is at capacity.

### Hard stop stiffness coefficient — Proportionality constant

1e4 MPa/m<sup>3</sup> (default) | positive scalar

Proportionality constant of the hard-stop contact pressure with respect to the liquid volume penetrated into the hard stop. The hard stops are used to restrict the liquid volume between zero and liquid chamber capacity.

### Fluid dynamic compressibility — Fluid compressibility

On (default) | Off

Whether to model any change in fluid density due to fluid compressibility. When **Fluid compressibility** is set to On, changes due to the mass flow rate into the block are calculated in addition to density changes due to changes in pressure. In the Isothermal Liquid Library, all blocks calculate density as a function of pressure.

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Gas-Charged Accumulator (IL)



# Spring-Loaded Accumulator

Hydraulic accumulator with spring used for energy storage



## Library

Accumulators

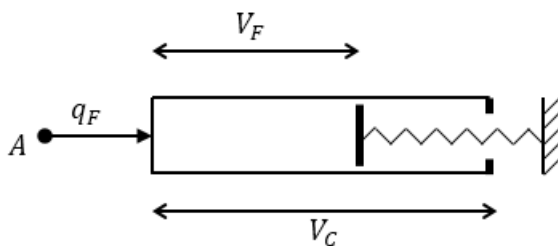
## Description

This block models a spring-loaded hydraulic fluid accumulator. The accumulator consists of a preloaded spring and a fluid chamber. The fluid chamber is connected to a hydraulic system.

As the fluid pressure at the accumulator inlet becomes greater than the preload pressure, fluid enters the accumulator and compresses the spring, storing hydraulic energy. A decrease in the fluid pressure causes the spring to decompress and discharge stored fluid into the system.

During typical operations, the spring pressure is equal to the pressure in the fluid chamber. However, if the pressure at the accumulator inlet drops below the preload pressure, the spring becomes isolated from the system. In this situation, the fluid chamber is empty and the spring pressure remains constant and equal to the preload pressure while the pressure at the accumulator inlet depends on the hydraulic system to which the accumulator is connected. If the pressure at the accumulator inlet builds up to the preload pressure or higher, fluid enters the accumulator again.

The motion of the spring is restricted by two hard stops that limit the expansion and contraction of the fluid volume. The fluid volume is limited when the fluid chamber is at capacity and when the fluid chamber is empty. The hard stops are modeled with finite stiffness and damping. This means that it is possible for the fluid volume to become negative or greater than the fluid chamber capacity, depending on the values of the hard-stop stiffness coefficient and the accumulator inlet pressure.



The diagram represents a spring-loaded accumulator. The fluid chamber is on the left and the spring is on the right. The distance between the left side and the spring defines the fluid volume ( $V_F$ ).

The hard stop contact pressure is modeled with a stiffness term and a damping term. The accumulator spring is assumed to have a linear relationship between the spring pressure and the fluid volume, with pressure balanced at the end of the spring:

$$p_{spr} - p_{pr} = K_{spr}V_F$$

$$p_F = p_{spr} + p_{HS}$$

$$K_{spr} = \frac{p_{max} - p_{pr}}{V_C}$$

$$p_{HS} = \begin{cases} K_S(V_F - V_C) + K_dq_F^\dagger(V_F - V_C) & \text{if } V_F \geq V_C \\ K_S V_F - K_dq_{\bar{F}} V_F & \text{if } V_F \leq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$q_F^\dagger = \begin{cases} q_F & \text{if } q_F \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$q_{\bar{F}} = \begin{cases} q_F & \text{if } q_F \leq 0 \\ 0 & \text{otherwise} \end{cases}$$

where

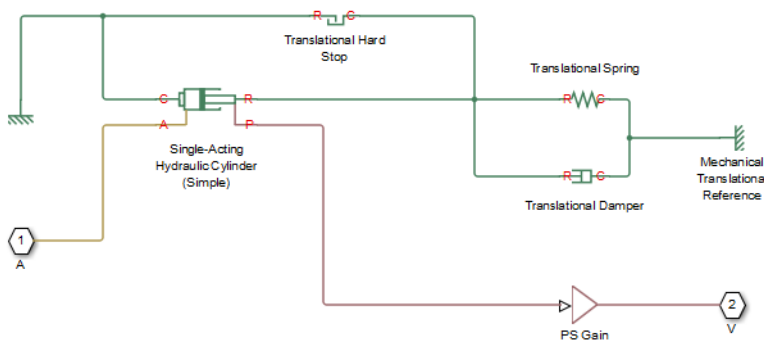
$V_F$	Volume of fluid in the accumulator
$V_{init}$	Initial volume of fluid in the accumulator
$V_C$	Fluid chamber capacity
$p_F$	Pressure at the accumulator inlet (gauge)
$p_{pr}$	Preload pressure (gauge)
$K_{spr}$	Spring gain coefficient
$p_{max}$	Pressure needed to fully fill the accumulator
$p_{spr}$	Pressure developed by the spring
$p_{HS}$	Hard-stop contact pressure
$K_s$	Hard-stop stiffness coefficient
$K_d$	Hard-stop damping coefficient
$q_F$	Fluid flow rate into the accumulator, which is positive if fluid flows into the accumulator

The flow rate into the accumulator is the rate of change of the fluid volume:

$$q_F = \frac{dV_F}{dt}$$

At  $t = 0$ , the initial condition is  $V_F = V_{init}$ , where  $V_{init}$  is the value you assign to the **Initial fluid volume** parameter.

The Spring-Loaded Accumulator block does not consider loading on the separator. To model additional effects, such as the separator inertia and friction, you can construct a spring-loaded accumulator as a subsystem or a composite component, similar to the block diagram below.



## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Basic Assumptions and Limitations

- The accumulator spring is assumed to behave linearly.
- Loading on the separator, such as inertia or friction, is not considered.
- Inlet hydraulic resistance is not considered.
- Fluid compressibility is not considered.

## Parameters

### Parameters Tab

#### Fluid chamber capacity

Amount of fluid that the accumulator can hold. The default value is  $8e-3 \text{ m}^3$ .

#### Preload pressure (gauge)

Spring pressure (gauge) when the fluid chamber is empty. The default value is  $10e5 \text{ Pa}$ .

#### Pressure at full capacity (gauge)

Spring pressure (gauge) when the fluid chamber is at capacity. The default value is  $30e5 \text{ Pa}$ .

#### Hard-stop stiffness coefficient

Proportionality constant of the hard-stop contact pressure with respect to the fluid volume penetrated into the hard stop. The hard stops are used to restrict the fluid volume between zero and fluid chamber capacity. The default value is  $1e10 \text{ Pa/m}^3$ .

#### Hard-stop damping coefficient

Proportionality constant of the hard-stop contact pressure with respect to the flow rate and the fluid volume penetrated into the hard stop. The hard stops are used to restrict the fluid volume between zero and fluid chamber capacity. The default value is  $1e10 \text{ Pa*s/m}^6$ .

## Ports

The block has one hydraulic conserving port associated with the accumulator inlet.

The flow rate is positive if fluid flows into the accumulator.

## Version History

Introduced in R2006a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Gas-Charged Accumulator

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Sudden Area Change

Sudden enlargement or contraction



## Library

Local Hydraulic Resistances

### Description

The Sudden Area Change block represents a local hydraulic resistance, such as a sudden cross-sectional area change. The resistance represents a sudden enlargement if fluid flows from inlet to outlet, or a sudden contraction if fluid flows from outlet to inlet. The block is based on the Local Resistance block. It determines the pressure loss coefficient and passes its value to the underlying Local Resistance block. The block offers two methods of parameterization: by applying semi-empirical formulas (with a constant value of the pressure loss coefficient) or by table lookup for the pressure loss coefficient based on the Reynolds number.

If you choose to apply the semi-empirical formulas, you provide geometric parameters of the resistance, and the pressure loss coefficient is determined automatically according to the following equations (see [1] on page 1-1698):

$$K_{SE} = K_{cor} \left( 1 - \frac{A_S}{A_L} \right)^2$$

$$K_{SC} = K_{cor} \cdot 0.5 \left( 1 - \frac{A_S}{A_L} \right)^{0.75}$$

where

$K_{SE}$	Pressure loss coefficient for the sudden enlargement, which takes place if fluid flows from inlet to outlet
$K_{SC}$	Pressure loss coefficient for the sudden contraction, which takes place if fluid flows from outlet to inlet
$K_{cor}$	Correction factor
$A_S$	Small area
$A_L$	Large area

If you choose to specify the pressure loss coefficient by a table, you have to provide a tabulated relationship between the loss coefficient and the Reynolds number. In this case, the loss coefficient is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

The pressure loss coefficient, determined by either of the two methods, is then passed to the underlying Local Resistance block, which computes the pressure loss according to the formulas

explained in the reference documentation for that block. The flow regime is checked in the underlying Local Resistance block by comparing the Reynolds number to the specified critical Reynolds number value, and depending on the result, the appropriate formula for pressure loss computation is used.

The Sudden Area Change block is bidirectional and computes pressure loss for both the direct flow (sudden enlargement) and return flow (sudden contraction). If the loss coefficient is specified by a table, the table must cover both the positive and the negative flow regions.

Connections A and B are conserving hydraulic ports associated with the block inlet and outlet, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure loss is determined as  $p = p_A - p_B$ .

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- If you select parameterization by the table-specified relationship  $K=f(Re)$ , the flow is assumed to be turbulent.

## Parameters

### Model parameterization

Select one of the following methods for block parameterization:

- **By semi-empirical formulas** — Provide geometrical parameters of the resistance. This is the default method.
- **Tabulated data – Loss coefficient vs. Reynolds number** — Provide tabulated relationship between the loss coefficient and the Reynolds number. The loss coefficient is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods. The table must cover both the positive and the negative flow regions.

### Small diameter

Internal diameter of the small port, **A**. The default value is 0.01 m.

### Large diameter

Internal diameter of the large port, **B**. The default value is 0.02 m. This parameter is used if **Model parameterization** is set to **By semi-empirical formulas**.

### Correction coefficient

Correction factor used in the formula for computation of the loss coefficient. The default value is 1. This parameter is used if **Model parameterization** is set to **By semi-empirical formulas**.

### Laminar transition specification

If **Model parameterization** is set to **By semi-empirical formulas**, select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.

- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 110. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Reynolds number vector

Specify the vector of input values for Reynolds numbers as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values are [-4000, -3000, -2000, -1000, -500, -200, -100, -50, -40, -30, -20, -15, -10, 10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000, 4000, 5000, 10000]. This parameter is used if **Model parameterization** is set to **By loss coefficient vs. Re table**.

### Loss coefficient vector

Specify the vector of the loss coefficient values as a one-dimensional array. The loss coefficient vector must be of the same size as the Reynolds numbers vector. The default values are [0.25, 0.3, 0.65, 0.9, 0.65, 0.75, 0.90, 1.15, 1.35, 1.65, 2.3, 2.8, 3.10, 5, 2.7, 1.8, 1.46, 1.3, 0.9, 0.65, 0.42, 0.3, 0.20, 0.40, 0.42, 0.25]. This parameter is used if **Model parameterization** is set to **By loss coefficient vs. Re table**.

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page. This parameter is used if **Model parameterization** is set to **By loss coefficient vs. Re table**.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) block reference page. This parameter is used if **Model parameterization** is set to `By loss coefficient vs. Re table`.

## Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Interpolation method**
- **Extrapolation method**
- **Laminar transition specification**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

## Global Parameters

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the resistance inlet.

B

Hydraulic conserving port associated with the resistance outlet.

## References

[1] Idelchik, I.E., *Handbook of Hydraulic Resistance*, CRC Begell House, 1994

## Version History

Introduced in R2006b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.



## **See Also**

Elbow | Gradual Area Change | Local Resistance | Pipe Bend | T-junction

## **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Sudden Area Change (TL)

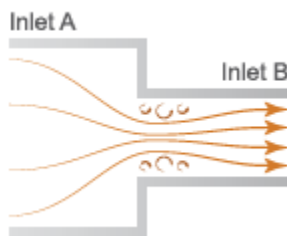
Sudden expansion or contraction in flow area

**Library:** Simscape / Fluids / Thermal Liquid / Pipes & Fittings



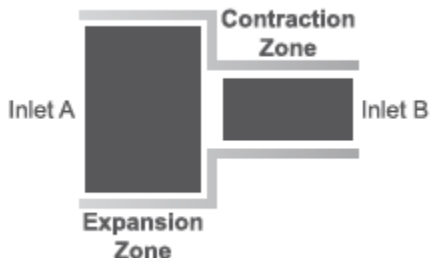
### Description

The Sudden Area Change (TL) block models the minor pressure losses due to a sudden change in flow cross-sectional area. The area change is a contraction from port **A** to port **B** and an expansion from port **B** to port **A**. This component is adiabatic. It does not exchange heat with its surroundings.



### Sudden Area Change Schematic

The pressure drop across a sudden expansion is primarily due to turbulence mixing in the expansion zone. Across a sudden contraction, it is primarily due to flow detachment at the contraction zone entrance. The figure shows the expansion and contraction zones of the sudden area change.



### Mass Balance

The mass conservation equation in the sudden area change is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  and  $\dot{m}_B$  are the mass flow rates into the sudden area change through ports A and B.

### Momentum Balance

The momentum conservation equation in the sudden area change is

$$p_A - p_B = \frac{\dot{m}^2}{2\rho} \left( \frac{1}{S_B^2} - \frac{1}{S_A^2} \right) + \phi_{Loss},$$

where:

- $p_A$  and  $p_B$  are the pressures at ports A and B.
- $\dot{m}$  is the average mass flow rate.
- $\rho$  is the average fluid density.
- $S_A$  and  $S_B$  are the flow cross-sectional areas at ports A and B.
- $\phi_{Loss}$  is the mechanical energy loss due to the sudden area change.

The mechanical energy loss is

$$\phi_{Loss} = K_{Loss} \frac{\dot{m}^2}{2\rho S_B^2},$$

where:

- $K_{Loss}$  is the loss coefficient.

If the **Loss coefficient specification** parameter is set to **Semi-empirical** formulation, the loss coefficient for a sudden expansion is computed as

$$K_{Loss} = K_e \left( 1 - \frac{S_B}{S_A} \right)^2,$$

while for a sudden contraction it is computed as

$$K_{Loss} = \frac{K_c}{2} \left( 1 - \frac{S_B}{S_A} \right),$$

where:

- $K_e$  is the correction factor in the expansion zone.
- $K_c$  is the correction factor in the contraction zone.

In the transition zone between sudden expansion and sudden contraction behavior, the loss coefficient is smoothed through a cubic polynomial function:

$$K_{Loss} = K_e \left( 1 - \frac{S_B}{S_A} \right)^2 + \lambda \left[ \frac{K_c}{2} \left( 1 - \frac{S_B}{S_A} \right) - K_e \left( 1 - \frac{S_B}{S_A} \right)^2 \right],$$

where

$$\lambda = 3\bar{m}^{-2} - 2\bar{m}^{-3},$$

and

$$\dot{m}_{Cr} = \text{Re}_{Cr} \sqrt{\frac{\pi}{4} S_B \mu}.$$

If the **Loss coefficient specification** parameter is set to **Tabulated data – Loss coefficient vs. Reynolds number**, the block obtains the loss coefficient from tabular data provided as a function of the Reynolds number.

### Energy Balance

The energy conservation equation in the sudden area change is

$$\phi_A + \phi_B = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are the energy flow rates into the sudden area change through ports A and B.

### Assumptions and Limitations

- The flow is incompressible. The fluid density is assumed constant in the sudden area change.

### Ports

#### Conserving

##### A – Section inlet

thermal liquid

Fluid entry or exit point to the area change section.

##### B – Section inlet

thermal liquid

Fluid entry or exit point to the area change section.

### Parameters

#### Local loss parameterization – Method of flow loss calculating

Semi-empirical (default) | Tabulated data - loss coefficient vs. Reynolds number

Parameterization for calculating the loss coefficient due to the sudden area change. Select **Semi-empirical formulation** to automatically compute the loss coefficient from the cross-sectional areas at ports **A** and **B**. Select **Tabulated data - Loss coefficient vs. Reynolds number** to specify a 1-D lookup table for the loss coefficient with respect to the flow Reynolds number.

#### Cross-sectional area at port A – Inlet area at A

0.02 m<sup>2</sup> (default) | positive scalar

Area normal to the direction of flow at inlet **A**. This value must be greater than the cross-sectional area at **B**.

#### Cross-sectional area at port B – Inlet area at B

0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the direction of flow at **B**. This value must be smaller than the cross-sectional area at **A**.

**Critical Reynolds number — Transitional Reynolds number associated with smallest area in section**

10 (default) | positive scalar

Reynolds number at which flow transitions between laminar and turbulent regimes in the contraction portion of the sudden area change. This parameter is visible only when the **Loss coefficient specification** parameter is set to Semi-empirical formulation.

**Contraction correction factor — Loss coefficient scaling factor**

1 (default) | positive scalar

Scaling factor for adjusting the loss coefficient value in the contraction portion of the sudden area change. The block multiplies the loss coefficient factor calculated from the semi-empirical expression by this factor. This parameter is visible only when the **Loss coefficient specification** parameter is set to Semi-empirical formulation.

**Expansion correction factor — Loss coefficient scaling factor**

1 (default) | positive scalar

Scaling factor for adjusting the loss coefficient value in the expansion portion of the sudden area change. The block multiplies the loss coefficient factor calculated from the semi-empirical expression by this factor. This parameter is visible only when the **Loss coefficient specification** parameter is set to Semi-empirical formulation.

**Reynolds number vector — Vector of Reynolds numbers for tabular parameterization**

[10, 20, 30, 40, 50, 100, 200, 500, 1000, 2000] (default) | vector

Vector of Reynolds numbers for the tabular parameterization of loss coefficients. You specify the **Contraction loss coefficient vector** and **Expansion loss coefficient vector** parameters at these Reynolds numbers.

This parameter is visible only when the **Loss coefficient specification** parameter is set to Tabulated data - Loss coefficient vs. Reynolds number.

**Contraction loss coefficient vector — Vector of loss coefficients for tabular parameterization**

[4, 2.7, 1.8, 1.46, 1.3, .9, .65, .42, .3, .2] (default) | 1-by-*n* vector

Vector of loss coefficients for the contraction portion of the area change. Specify the loss coefficients at the Reynolds numbers in the **Reynolds number vector** parameter. The block uses the Reynolds number and loss coefficient vectors to construct a 1-D lookup table.

This parameter is visible only when the **Loss coefficient specification** parameter is set to Tabulated data – Loss coefficient vs. Reynolds number.

**Expansion loss coefficient vector — Vector of loss coefficients for tabular parameterization**

[4, 2.3, 1.65, 1.35, 1.15, .9, .75, .65, .9, .65] (default) | 1-by-*n* vector

Vector of loss coefficients for the expansion portion of the area change. Specify the loss coefficients at the Reynolds numbers in the **Reynolds number vector** parameter. The block uses the Reynolds number and loss coefficient vectors to construct a 1-D lookup table.

This parameter is visible only when the **Loss coefficient specification** parameter is set to Tabulated data – Loss coefficient vs. Reynolds number.

## **Version History**

**Introduced in R2016a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Pipe (TL)

# Swash Plate

Swash plate mechanism



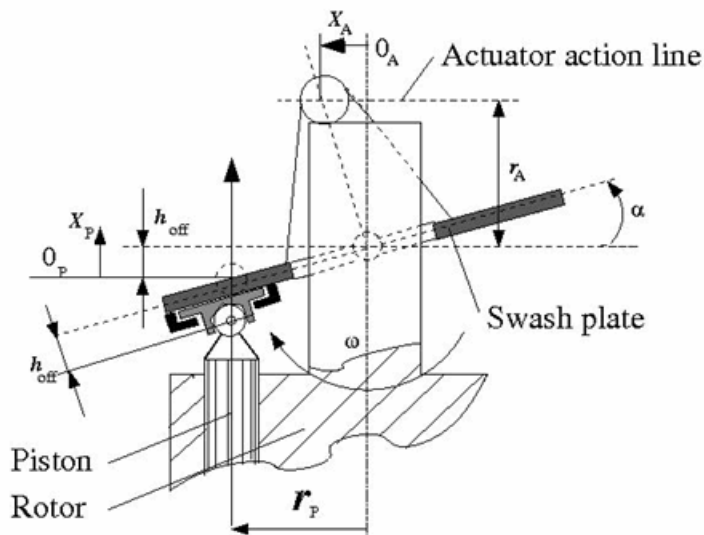
## Library

Pumps and Motors

## Description

Note that this reference page is for the Hydraulics (Isothermal) Liquid library block. For the Isothermal Liquid library block, see Swash Plate.

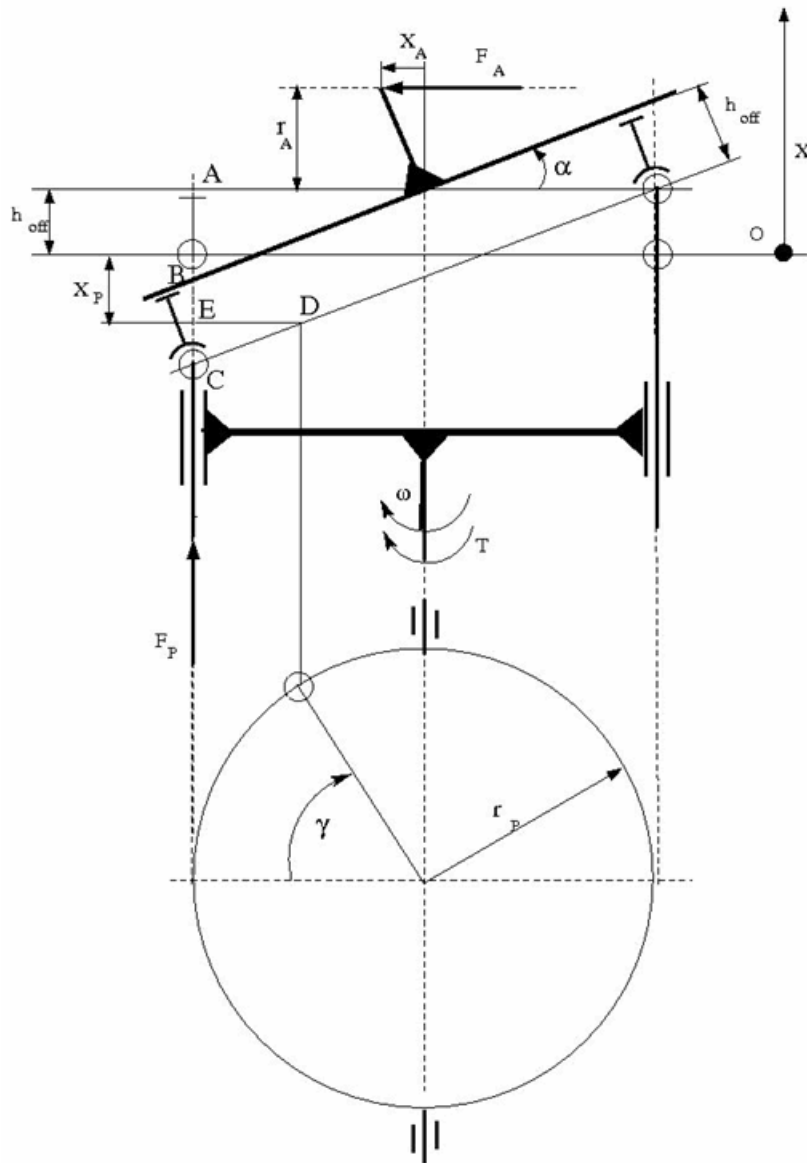
The Swash Plate block is a model of a swash plate mechanism used in axial-piston hydraulic pumps and motors to convert translational motion of a piston into rotational motion of a drive shaft. The mechanism is a combination of a cylinder block or rotor, with the piston fitted inside, and an angled swash plate.



The angular position of the plate is controlled by an actuator, usually a servo cylinder, acting along the actuator action line (marked in the preceding diagram). The distance between the actuator line and the swash plate at zero angle is equal to the actuator arm length  $r_A$ . The pistons are offset by  $h_{\text{off}}$  from the swash plate. The swash plate angle can be changed to increase or decrease the piston stroke. As the rotor turns, the piston slides on the swash plate, which causes the piston to reciprocate. The sliding contact between the piston and the swash plate is maintained by the guideway shown in the diagram.

In a hydraulic machine, the piston moves along the slots in the porting plate (not shown in the preceding diagram) thus being periodically connected to either the intake or the discharge port of the machine. The model simulates a single piston interacting with the swash plate. Mechanically, the mechanism performs summation of two motions, caused by rotation of the swash plate with respect to its axis and rotation of the rotor, and converts them into displacement of the piston.

The following illustration shows the calculation diagram of the mechanism.



The positive direction of the actuator is assumed to be directed to the left from the vertical axis, while the positive direction of the piston motion is directed upward, as it is shown in the diagram. The reference point for both motions corresponds to the plate being perpendicular to the rotor axis. As far as the angular motion of the rotor is concerned, the clockwise rotation (looking from the top) is assumed to be positive.



The piston displacement at arbitrary rotor rotation angle  $\gamma$  and actuator displacement  $x_A$  is determined from the relationship:

$$x_P = -(AB - h_{off} + BC + DE \cdot tg\alpha)$$

$$tg\alpha = \frac{x_A}{r_A}$$

which, after minor rearrangement, yields:

$$x_P = -\frac{r_P}{r_A}x_A \cos(\gamma + \beta) - h_{off} \left( \sqrt{1 + \frac{x_A^2}{r_A^2}} - 1 \right) \quad (1-12)$$

$$\gamma = \omega \cdot t$$

where

$x_P$	Piston displacement
$x_A$	Actuator displacement
$r_P$	Cylinder block pitch radius
$r_A$	Actuator arm
$\gamma$	Rotor angle of rotation
$h_{off}$	Piston offset
$\beta$	Piston phase angle
$\omega$	Rotor angular velocity
$t$	Time

The kinematic relationship between piston and actuator displacement must be converted into a relationship between the basic Across variables for the physical network representation, that is, velocities:

$$V_P = \frac{dx_P}{dt} = -\frac{r_P}{r_A}V_A \cos(\gamma + \beta) + \frac{r_P}{r_A}x_A \omega \sin(\gamma + \beta) - \frac{h_{off}}{r_A^2} \frac{x_A V_A}{\sqrt{1 + \frac{x_A^2}{r_A^2}}}$$

where

$V_P$	Piston velocity
$V_A$	Actuator velocity

The inertia properties of the mechanism are assumed to be negligible. Therefore, any state of the mechanism can be considered as equilibrium. According to the principle of virtual work, if the system is in equilibrium the aggregate work of all the applied forces and torques on the system virtual displacements is equal to zero. For the mechanism under consideration, the principle of virtual work yields:

$$F_P \delta x_P + F_A \delta x_A + (T - T_{res}) \delta \gamma = 0 \quad (1-13)$$

where

$F_P$	Piston force
$F_A$	Actuator force
$T$	Rotor torque
$T_{res}$	Resistance torque acting on the rotor due to viscous friction

Virtual displacements  $\delta x_P$ ,  $\delta x_A$ , and  $\delta \gamma$  are determined from “Equation 1-12” and substituted into “Equation 1-13”. Since virtual displacements  $\delta x_A$  and  $\delta \gamma$  are independent, any of them can be equal to zero. As a result, we obtain two more equations of the mechanism:

$$F_A = \frac{r_P}{r_A} F_P \cos(\gamma + \beta) + \frac{h_{off}}{r_A^2} \frac{x_A}{\sqrt{1 + \frac{x_A^2}{r_A^2}}} F_P$$

$$T = -\frac{r_P}{r_A} x_A \cdot F_P \cdot \sin(\gamma + \beta) + T_{res}$$

The resistance torque is:

$$T_{res} = \mu \cdot r_P \cdot \omega$$

where  $\mu$  is the viscous friction coefficient in the contact between the piston and the plate.

The final set of equations describing the swash plate mechanism takes the form:

$$V_P = \frac{dx_P}{dt} = -\frac{r_P}{r_A} V_A \cos(\gamma + \beta) + \frac{r_P}{r_A} x_A \omega \sin(\gamma + \beta) - \frac{h_{off}}{r_A^2} \frac{x_A V_A}{\sqrt{1 + \frac{x_A^2}{r_A^2}}}$$

$$F_A = \frac{r_P}{r_A} F_P \cos(\gamma + \beta) + \frac{h_{off}}{r_A^2} \frac{x_A}{\sqrt{1 + \frac{x_A^2}{r_A^2}}} F_P$$

$$T = -\frac{r_P}{r_A} x_A \cdot F_P \cdot \sin(\gamma + \beta) + \mu \cdot r_P \cdot F_P$$

Connection P is a mechanical translational conserving port associated with the tip of the piston. Connection S is a mechanical rotational conserving port associated with the drive shaft, which is connected to the cylinder block. Connection A is a mechanical translational conserving port associated with the swash plate actuator.

## Basic Assumptions and Limitations

- The model accounts for the viscous friction in the piston-plate contact.
- No inertial effects are considered.
- The plate angular displacements are considered to be small.
- The joint between the piston and the plate permanently maintains contact between the piston and the plate.

## Parameters

### Swash plate actuator arm

The distance between the actuator line of action and the center of the rotor rotation. The parameter must be greater than zero. The default value is 0.065 m.

### Piston pitch radius

The radius of the pitch circle where the pistons are located, that is, the cylinder block pitch radius. The parameter must be greater than zero. The default value is 0.05 m.

### Piston offset from the plate

The offset between the piston tip and the swash plate. The parameter must be greater than or equal to zero. The default value is 0.

### Phase angle

Parameter sets the piston initial angular position with respect to the reference point which corresponds to the zero angle. The default value is 0.

### Actuator initial displacement

Parameter sets the initial position of the actuator with respect to the reference point which corresponds to the plate being perpendicular to the axis of rotor rotation. The default value is 0.

### Viscous friction coefficient

The parameter specifies the coefficient of viscous friction in the contact between the piston and the plate. The parameter must be greater than zero. The default value is 50 N/(m/s).

## Ports

The block has the following ports:

A

Mechanical translational conserving port associated with the actuator joint.

P

Mechanical translational conserving port associated with the tip of the piston.

S

Mechanical rotational conserving port associated with the drive shaft.

## Examples

The “Hydraulic Axial-Piston Pump with Load-Sensing and Pressure-Limiting Control” example models a test rig designed to investigate interaction between an axial-piston pump and a typical control unit, simultaneously performing the load-sensing and pressure-limiting functions. To assure required accuracy, the model of the pump must account for such features as interaction between pistons, swash plate, and porting plate, which makes it necessary to build a detailed pump model.

## Version History

Introduced in R2011a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Porting Plate Variable Orifice

### **Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Swash Plate

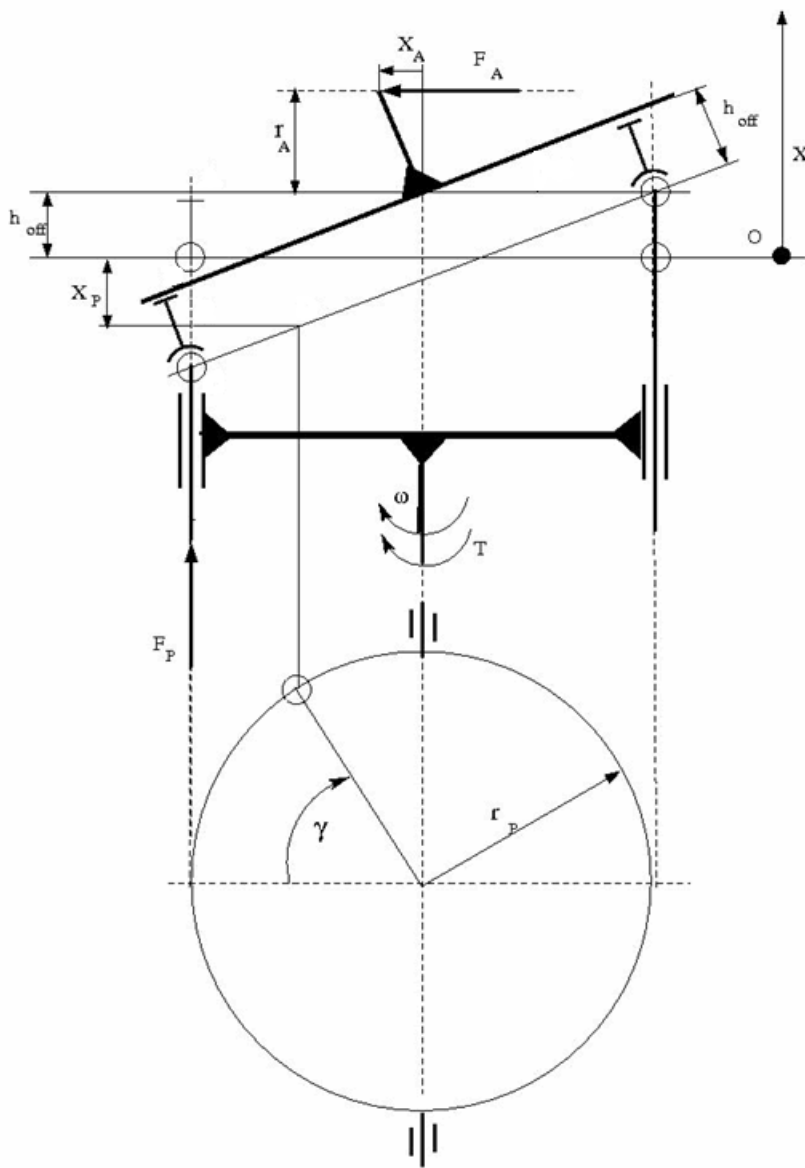
Swash plate in a single-piston, isothermal axial piston pump

**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors /  
Auxiliary Components



## Description

The Swash Plate block models a single, piston-actuated swash plate within an axial-piston pump. It translates linear actuation into rotational motion that, when connected to the Valve Plate Orifice (IL) block, periodically connects the piston with the pump intake and discharge. You can connect multiple swash plate blocks to multiple pistons.



### Schematic of a Swash Plate Within an Axial-Piston Pump Unit

#### Force Balance

The plate is in dynamic equilibrium if the net work by the piston, actuator, and plate is zero:

$$F_P \delta_P + F_A \delta_A + (\tau - \tau_{res}) \delta_y = 0,$$

where:

- $F_P \delta_P$  is the work done due to piston displacement.
- $F_A \delta_A$  is the work done due to actuator displacement.
- $(\tau - \tau_{res}) \delta_y$  is the work done due to the net plate torque tangent to plate motion.

The plate torque is:

$$\tau = -\frac{r_P}{r_A}x_A F_P \sin\gamma + \tau_{res},$$

where:

- $r_P$  is the **Cylinder block pitch radius**.
- $r_A$  is the **Swash plate actuator arm**.
- $X_A$  is the actuator displacement.
- $F_P$  is the piston force.
- $\gamma$  is the plate angular displacement.

The viscous friction torque, or the resistance to motion due to plate-piston contact, is:

$$\tau_{res} = \mu_{viscous}\omega r_P^2,$$

where:

- $\mu_{viscous}$  is the **Viscous friction coefficient**.
- $\omega$  is the rotor angular velocity.

### Piston Dynamics

The piston displacement,  $x$ , is proportional to the actuator displacement:

$$x = -h_{off}\left(\sqrt{1 + \frac{x_A^2}{r_A^2}} - 1\right) - \frac{r_P}{r_A}x_A \cos\gamma,$$

where  $h_{off}$  is the **Piston offset from the plate**. Displacement is positive if it moves toward the cylinder block.

The piston velocity is:

$$V_P = \frac{r_P}{r_A}x_A\omega\sin(\gamma) - \frac{r_P}{r_A}V_A\cos\gamma - \frac{h_{off}}{r_A^2}\frac{x_A V_A}{\sqrt{1 + \frac{x_A^2}{r_A^2}}},$$

where  $V_A$  is the actuator velocity.

### Assumptions and Limitations

This block accounts for the effect of viscous friction between the piston and plate, but neglects plate and fluid inertia.

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**Note** This reference page is for the Isothermal Liquid library block. For the Hydraulics (Isothermal) Liquid library block, see Swash Plate.

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## Ports

### Conserving

**A – Mechanical port associated with actuator**

mechanical translational

Swash plate actuator velocity and force.

**P – Mechanical port associated with piston**

mechanical translational

Piston end velocity and force.

**S – Mechanical port associated with shaft**

mechanical rotational

Drive shaft angular velocity and torque. Rotation is relative to the environment.

## Parameters

**Swash plate actuator arm – Length of actuator extension**

0.065 m (default) | positive scalar

Length of fully extended actuator arm.

**Cylinder block pitch radius – Cylinder pitch radius**

0.05 m (default) | positive scalar

Pitch radius of the rotating cylinder.

**Piston offset from the plate – Resting piston offset**

0 m (default) | scalar

Piston offset when the actuator is in neutral position. A positive, nonzero value indicates a partially retracted piston. A negative, nonzero value indicates an extended piston that remains within the cylinder block during an initial actuator displacement away from the cylinder.

**Viscous friction coefficient – Torque viscous friction coefficient**

50 N/(m/s) (default) | positive scalar

Coefficient used in the equation for torque due to viscous friction.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.



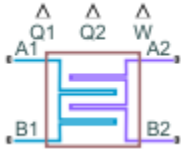
**See Also**

Valve Plate Orifice (IL)

## System-Level Condenser Evaporator (2P-MA)

Heat exchanger between two-phase fluid and moist air networks, with model based on performance data

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The System-Level Condenser Evaporator (2P-MA) block models a heat exchanger between a two-phase fluid network and a moist air network.

The block can act as a condenser or as an evaporator in a refrigeration system, depending on the direction of heat transfer. The block model is based on performance data from the heat exchanger datasheet, rather than on the detailed geometry of the exchanger, and therefore lets you easily adjust the size and performance of the heat exchanger during design iterations, or model heat exchangers with uncommon geometries. You can also use this block to model heat exchangers with a certain level of performance at an early design stage, when detailed geometry data is not yet available.

You parameterize the block by the nominal operating condition. The heat exchanger is sized to match the specified performance at the nominal operating condition at steady state.

The Two-Phase Fluid 1 side approximates the liquid zone, mixture zone, and vapor zone based on the change in enthalpy along the flow path. The Moist Air 2 side models water vapor condensation based on convective water vapor mass transfer with the heat transfer surface. Condensed water is removed from the moist air flow.

This block is similar to the Condenser Evaporator (2P-MA) block but uses a different parameterization model. The table provides a comparison of the two blocks, to help you choose the right block for your application.

Condenser Evaporator (2P-MA)	System-Level Condenser Evaporator (2P-MA)
Block parameters are based on the heat exchanger geometry	Block parameters are based on performance and operating conditions
Heat exchanger geometry may be limited by the available geometry parameter options	Model is independent of the specific heat exchanger geometry
You can adjust the block for different performance requirements by tuning geometry parameters, such as fin sizes and tube lengths	You can adjust the block for different performance requirements by directly specifying the desired heat and mass flow rates
Lets you select between parallel, counter, or cross flow configurations	Lets you select between parallel, counter, or cross flow arrangement at nominal operating conditions, to help with sizing

Condenser Evaporator (2P-MA)	System-Level Condenser Evaporator (2P-MA)
Predictively accurate results over a wide range of operating conditions, subject to the applicability of the E-NTU equations and the heat transfer coefficient correlations	Very accurate results around the specified operating condition; accuracy may decrease far away from the specified operating conditions
Heat transfer calculations account for the variation of temperature along the flow path by using the E-NTU model	Heat transfer calculations approximate the variation of temperature along the flow path by dividing it into three segments
Accounts for different fluid properties and heat transfer coefficients for subcooled liquid, liquid-vapor mixture, and superheated vapor	Accounts for different fluid properties and heat transfer coefficients for subcooled liquid, liquid-vapor mixture, and superheated vapor
Keeps track of variable zone length fractions for subcooled liquid, liquid-vapor mixture, and superheated vapor regions based on the geometry	Approximates the effect of subcooled liquid, liquid-vapor mixture, and superheated vapor regions using weighting factors based on the difference in enthalpy between inlet and outlet
Accounts for water vapor condensation and the latent heat on the moist air flow	Accounts for water vapor condensation and the latent heat on the moist air flow
Does not model the wall thermal mass; you can approximate the effect by connecting a pipe block with a thermal mass downstream	Includes an option to model the wall thermal mass

### Heat Transfer

The two-phase fluid flow and the moist air flow are each divided into three segments of equal size. Heat transfer between the fluids is calculated in each segment. For simplicity, the equation for one segment is shown here.

If the wall thermal mass is off, then the heat balance in the heat exchanger is

$$Q_{seg, 2P} + Q_{seg, MA} = 0,$$

where:

- $Q_{seg, 2P}$  is the heat flow rate from the wall (that is, the heat transfer surface) to the two-phase fluid in the segment.
- $Q_{seg, MA}$  is the heat flow rate from the wall to the moist air in the segment.

If the wall thermal mass is on, then the heat balance in the heat exchanger is

$$Q_{seg, 2P} + Q_{seg, MA} = - \frac{M_{wall} c_{p, wall}}{N} \frac{dT_{seg, wall}}{dt},$$

where:

- $M_{wall}$  is the mass of the wall.
- $c_{p, wall}$  is the specific heat of the wall.
- $N = 3$  is the number of segments.
- $T_{seg, wall}$  is the average wall temperature in the segment.
- $t$  is time.

The heat flow rate from the wall to the two-phase fluid in the segment is

$$Q_{seg, 2P} = UA_{seg, 2P}(T_{seg, wall} - T_{seg, 2P}),$$

where:

- $UA_{seg, 2P}$  is the weighted-average heat transfer conductance for the two-phase fluid in the segment.
- $T_{seg, 2P}$  is the weighted-average fluid temperature for the two-phase fluid in the segment.

The heat flow rate from the wall to the moist air in the segment is

$$Q_{seg, MA} = \frac{UA_{seg, MA}}{\bar{c}_{pseg, MA}}(\bar{h}_{seg, wall} - \bar{h}_{seg, MA}) + \dot{m}_{w, seg, cond}h_{l, wall}$$

where:

- $UA_{seg, MA}$  is the heat transfer conductance for the moist air in the segment.
- $\bar{c}_{pseg, MA}$  is the moist air mixture specific heat per unit mass of dry air and trace gas in the segment.
- $\bar{h}_{seg, wall}$  is the moist air mixture enthalpy per unit mass of dry air and trace gas at the average wall segment temperature.
- $\bar{h}_{seg, MA}$  is the moist air mixture enthalpy per unit mass of dry air and trace gas in the segment.
- $\dot{m}_{w, seg, cond}$  is the rate of water vapor condensation on the wall surface.
- $h_{l, wall}$  is the specific enthalpy of liquid water at the average wall segment temperature.

Using mixture enthalpy in this equation accounts for both differences in temperature and differences in moisture due to condensation [3].

---

**Note** For the moist air quantities, the bar above the symbols indicates that they are quantities for mixture divided by the mass of dry air and trace gas only, as opposed to dividing by the mass of the whole mixture. The whole mixture includes dry air, water vapor, and trace gas.

---

### Two-Phase Fluid Heat Transfer Correlation

If the segment is subcooled liquid, then the heat transfer conductance is

$$UA_{seg, L, 2P} = a_{L, 2P}(Re_{seg, L, 2P})^{b_{2P}}(Pr_{seg, L, 2P})^{c_{2P}}k_{seg, L, 2P}\frac{G_{2P}}{N},$$

where:

- $a_{L, 2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg, L, 2P}$  is the average liquid Reynolds number for the segment.
- $Pr_{seg, L, 2P}$  is the average liquid Prandtl number for the segment.
- $k_{seg, L, 2P}$  is the average liquid thermal conductivity for the segment.
- $G_{2P}$  is the geometry scale factor for the two-phase fluid side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average liquid Reynolds number is

$$Re_{seg,L,2P} = \frac{\dot{m}_{seg,2P} D_{ref,2P}}{\mu_{seg,L,2P} S_{ref,2P}},$$

where:

- $\dot{m}_{seg,2P}$  is the mass flow rate through the segment.
- $\mu_{seg,L,2P}$  is the average liquid dynamic viscosity for the segment.
- $D_{ref,2P}$  is an arbitrary reference diameter.
- $S_{ref,2P}$  is an arbitrary reference flow area.

---

**Note** The  $D_{ref,2P}$  and  $S_{ref,2P}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,L,2P}$  nondimensional. The values of  $D_{ref,2P}$  and  $S_{ref,2P}$  are arbitrary because the  $G_{2P}$  calculation overrides these values.

---

Similarly, if the segment is superheated vapor, then the heat transfer conductance is

$$UA_{seg,V,2P} = a_{V,2P} (Re_{seg,V,2P})^{b_{2P}} (Pr_{seg,V,2P})^{c_{2P}} k_{seg,V,2P} \frac{G_{2P}}{N},$$

where:

- $a_{V,2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,V,2P}$  is the average vapor Reynolds number for the segment.
- $Pr_{seg,V,2P}$  is the average vapor Prandtl number for the segment.
- $k_{seg,V,2P}$  is the average vapor thermal conductivity for the segment.

The average vapor Reynolds number is

$$Re_{seg,V,2P} = \frac{\dot{m}_{seg,2P} D_{ref,2P}}{\mu_{seg,V,2P} S_{ref,2P}},$$

where  $\mu_{seg,V,2P}$  is the average vapor dynamic viscosity for the segment.

If the segment is liquid-vapor mixture, then the heat transfer conductance is

$$UA_{seg,M,2P} = a_{M,2P} (Re_{seg,SL,2P})^{b_{2P}} CZ (Pr_{seg,SL,2P})^{c_{2P}} k_{seg,SL,2P} \frac{G_{2P}}{N},$$

where:

- $a_{M,2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,SL,2P}$  is the saturated liquid Reynolds number for the segment.
- $Pr_{seg,SL,2P}$  is the saturated liquid Prandtl number for the segment.
- $k_{seg,SL,2P}$  is the saturated liquid thermal conductivity for the segment.
- CZ is the Cavallini and Zecchin term.

The saturated liquid Reynolds number is

$$Re_{seg, SL, 2P} = \frac{\dot{m}_{seg, 2P} D_{ref, 2P}}{\mu_{seg, SL, 2P} S_{ref, 2P}},$$

where  $\mu_{seg, SL, 2P}$  is the saturated liquid dynamic viscosity for the segment.

The Cavallini and Zecchin term is

$$CZ = \frac{\left( \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, out, 2P} + 1) \right)^{1 + b_{2P}} - \left( \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, in, 2P} + 1) \right)^{1 + b_{2P}}}{(1 + b_{2P}) \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, out, 2P} - x_{seg, in, 2P})},$$

where:

- $\nu_{seg, SL, 2P}$  is the saturated liquid specific volume for the segment.
- $\nu_{seg, SV, 2P}$  is the saturated vapor specific volume for the segment.
- $x_{seg, in, 2P}$  is the vapor quality at the segment inlet.
- $x_{seg, out, 2P}$  is the vapor quality at the segment outlet.

The expression is based on the work of Cavallini and Zecchin [5], which derives a heat transfer coefficient correlation at a local vapor quality  $x$ . Equations for the liquid-vapor mixture are obtained by averaging Cavallini and Zecchin's correlation over the segment from  $x_{seg, in, 2P}$  to  $x_{seg, out, 2P}$ .

### Two-Phase Fluid Weighted Average

The two-phase fluid flow through a segment may not be entirely represented as either subcooled liquid, superheated vapor, or liquid-vapor mixture. Instead, each segment may consist of a combination of these. The block approximates this condition by computing weighting factors ( $w_L$ ,  $w_V$ , and  $w_M$ ) based on the change in specific enthalpy across the segment and the saturated liquid and vapor specific enthalpies. The block assumes that the specific enthalpy across the segment varies piecewise linearly from inlet to outlet, with the breakpoints corresponding to the saturation boundaries for liquid and vapor. The zone with a larger heat transfer coefficient has a steeper slope than the zone with a lower heat transfer coefficient.

$$w_L = \frac{\Delta_L}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_V = \frac{\Delta_V}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_M = 1 - w_L - w_V$$

$$\Delta_L = |\min(h_{seg, out, 2P}, h_{seg, SL, 2P}) - \min(h_{seg, in, 2P}, h_{seg, SL, 2P})| \cdot UA_{seg, M, 2P} \cdot UA_{seg, V, 2P}$$

$$\Delta_M = |\min(\max(h_{seg, out, 2P}, h_{seg, SL, 2P}), h_{seg, SV, 2P}) - \min(\max(h_{seg, in, 2P}, h_{seg, SL, 2P}), h_{seg, SV, 2P})| \cdot UA_{seg, L, 2P} \cdot U$$

$$\Delta_V = |\max(h_{seg, out, 2P}, h_{seg, SV, 2P}) - \max(h_{seg, in, 2P}, h_{seg, SV, 2P})| \cdot UA_{seg, L, 2P} \cdot UA_{seg, M, 2P}$$

where:

- $h_{seg, in, 2P}$  is the specific enthalpy at the segment inlet.
- $h_{seg, out, 2P}$  is the specific enthalpy at the segment outlet.

- $h_{seg,SL,2P}$  is the saturated liquid specific enthalpy for the segment.
- $h_{seg,SV,2P}$  is the saturated vapor specific enthalpy for the segment.

The weighted-average two-phase fluid heat transfer conductance for the segment is therefore

$$UA_{seg,2P} = w_L(UA_{seg,L,2P}) + w_V(UA_{seg,V,2P}) + w_M(UA_{seg,M,2P}).$$

The weighted-average fluid temperature for the segment is

$$T_{seg,2P} = \frac{w_L(UA_{seg,L,2P})T_{seg,L,2P} + w_V(UA_{seg,V,2P})T_{seg,V,2P} + w_M(UA_{seg,M,2P})T_{seg,M,2P}}{UA_{seg,2P}},$$

where:

- $T_{seg,L,2P}$  is the average liquid temperature for the segment.
- $T_{seg,V,2P}$  is the average vapor temperature for the segment.
- $T_{seg,M,2P}$  is the average mixture temperature for the segment, which is the saturated liquid temperature.

### Moist Air Heat Transfer Correlation

The heat transfer conductance is

$$UA_{seg,MA} = a_{MA}(Re_{seg,MA})^{b_{MA}}(Pr_{seg,MA})^{c_{MA}}k_{seg,MA}\frac{G_{MA}}{N},$$

where:

- $a_{MA}$ ,  $b_{MA}$ , and  $c_{MA}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,MA}$  is the average Reynolds number for the segment.
- $Pr_{seg,MA}$  is the average Prandtl number for the segment.
- $k_{seg,MA}$  is the average thermal conductivity for the segment.
- $G_{MA}$  is the geometry scale factor for the moist air side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average Reynolds number is

$$Re_{seg,MA} = \frac{\dot{m}_{seg,MA}D_{ref,MA}}{\mu_{seg,MA}S_{ref,MA}},$$

where:

- $\dot{m}_{seg,MA}$  is the mass flow rate through the segment.
- $\mu_{seg,MA}$  is the average dynamic viscosity for the segment.
- $D_{ref,MA}$  is an arbitrary reference diameter.
- $S_{ref,MA}$  is an arbitrary reference flow area.

---

**Note** The  $D_{ref,MA}$  and  $S_{ref,MA}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,MA}$  nondimensional. The values of  $D_{ref,MA}$  and  $S_{ref,MA}$  are arbitrary because the  $G_{MA}$  calculation overrides these values.

---

### Moist Air Condensation

The equation describing the heat flow rate from the wall to the moist air in the segment (the last equation in the “Heat Transfer” on page 1-1717 section) uses the average moist air mixture enthalpy,  $\bar{h}_{seg,MA}$ , and the wall segment moist air mixture enthalpy,  $\bar{h}_{seg,wall}$ .

The average moist air mixture enthalpy is based on the temperature and humidity of the moist air flow through the segment:

$$\bar{h}_{seg,MA} = h_{seg,ag,MA} + W_{seg,MA}h_{seg,w,MA}$$

where:

- $h_{seg,ag,MA}$  is the average specific enthalpy of dry air and trace gas for the segment.
- $h_{seg,w,MA}$  is the average specific enthalpy of water vapor for the segment.
- $W_{seg,MA}$  is the humidity ratio of the segment.

The wall segment moist air mixture enthalpy is based on the temperature and humidity at the wall segment:

$$\bar{h}_{seg,wall} = h_{seg,ag,wall} + W_{seg,wall}h_{seg,w,wall}$$

where:

- $h_{seg,ag,wall}$  is the specific enthalpy of dry air and trace gas at the wall segment temperature.
- $h_{seg,w,wall}$  is the specific enthalpy of water vapor at the wall segment temperature.
- $W_{seg,wall}$  is the humidity ratio at the wall segment:

$$W_{seg,wall} = \min(W_{seg,MA}, W_{seg,s,wall})$$

where  $W_{seg,s,wall}$  is the saturated humidity ratio at the wall segment temperature. In other words, the humidity ratio at the wall is the same as the humidity ratio of the moist air flow but not more than the maximum that can be supported at the wall segment temperature.

When  $W_{seg,s,wall} < W_{seg,MA}$ , water vapor condensation occurs on the wall surface. The rate of water vapor condensation is

$$\dot{m}_{w,seg,cond} = \frac{UA_{seg,MA}}{c_{pseg,MA}}(W_{seg,MA} - W_{seg,wall})$$

The condensed water is assumed to be drained from the wall surface and is thus removed from the moist air flow downstream.

### Pressure Loss

The pressure losses on the two-phase fluid side are



$$p_{A,2P} - p_{2P} = \frac{K_{2P} \dot{m}_{A,2P} \sqrt{\dot{m}_{A,2P}^2 + \dot{m}_{thres,2P}^2}}{2 \rho_{avg,2P}}$$

$$p_{B,2P} - p_{2P} = \frac{K_{2P} \dot{m}_{B,2P} \sqrt{\dot{m}_{B,2P}^2 + \dot{m}_{thres,2P}^2}}{2 \rho_{avg,2P}}$$

where:

- $p_{A,2P}$  and  $p_{B,2P}$  are the pressures at ports **A1** and **B1**, respectively.
- $p_{2P}$  is internal two-phase fluid pressure at which the heat transfer is calculated.
- $\dot{m}_{A,2P}$  and  $\dot{m}_{B,2P}$  are the mass flow rates into ports **A1** and **B1**, respectively.
- $\rho_{avg,2P}$  is the average two-phase fluid density over all segments.
- $\dot{m}_{thres,2P}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{2P}$ , so that  $p_{A,2P} - p_{B,2P}$  matches the nominal pressure loss at the nominal mass flow rate.

The pressure losses on the moist air side are

$$p_{A,MA} - p_{MA} = \frac{K_{MA} \dot{m}_{A,MA} \sqrt{\dot{m}_{A,MA}^2 + \dot{m}_{thres,MA}^2}}{2 \rho_{avg,2P}}$$

$$p_{B,MA} - p_{MA} = \frac{K_{MA} \dot{m}_{B,MA} \sqrt{\dot{m}_{B,MA}^2 + \dot{m}_{thres,MA}^2}}{2 \rho_{avg,MA}}$$

where:

- $p_{A,MA}$  and  $p_{B,MA}$  are the pressures at ports **A2** and **B2**, respectively.
- $p_{MA}$  is internal moist air pressure at which the heat transfer is calculated.
- $\dot{m}_{A,MA}$  and  $\dot{m}_{B,MA}$  are the mass flow rates into ports **A2** and **B2**, respectively.
- $\rho_{avg,MA}$  is the average moist air density over all segments.
- $\dot{m}_{thres,MA}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{MA}$ , so that  $p_{A,MA} - p_{B,MA}$  matches the nominal pressure loss at the nominal mass flow rate.

### Two-Phase Fluid Mass and Energy Conservation

The mass conservation equation for the overall two-phase fluid flow is

$$\left( \frac{dp_{2P}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,2P}}{\partial p} \right) + \sum_{segments} \left( \frac{du_{seg,2P}}{dt} \frac{\partial \rho_{seg,2P}}{\partial u} \right) \right) \frac{V_{2P}}{N} = \dot{m}_{A,2P} + \dot{m}_{B,2P},$$

where:

- $\frac{\partial \rho_{seg,2P}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,2P}}{\partial u}$  is the partial derivative of density with respect to specific internal energy for the segment.

- $u_{seg,2P}$  is the specific internal energy for the segment.
- $V_{2P}$  is the total two-phase fluid volume.

The summation is over all segments.

---

**Note** Although the two-phase fluid flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{2P}$ . That is why  $p_{2P}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\frac{du_{seg,2P}}{dt} \frac{M_{2P}}{N} + u_{seg,2P}(\dot{m}_{seg,in,2P} - \dot{m}_{seg,out,2P}) = \Phi_{seg,in,2P} - \Phi_{seg,out,2P} + Q_{seg,2P},$$

where:

- $M_{2P}$  is the total two-phase fluid mass.
- $\dot{m}_{seg,in,2P}$  and  $\dot{m}_{seg,out,2P}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg,in,2P}$  and  $\Phi_{seg,out,2P}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A,2P}$  and  $\dot{m}_{B,2P}$ .

### Moist Air Mass and Energy Conservation

The mass conservation for the overall moist air mixture flow is

$$\left( \frac{dp_{MA}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,MA}}{\partial p} \right) + \sum_{segments} \left( \frac{dT_{seg,MA}}{dt} \frac{\partial \rho_{seg,MA}}{\partial T} + \frac{dx_{w,seg,MA}}{dt} \frac{\partial \rho_{seg,MA}}{\partial x_w} + \frac{dx_{g,seg,MA}}{dt} \frac{\partial \rho_{seg,MA}}{\partial x_g} \right) \right) \frac{V_{MA}}{N} = \dot{m}_{A,MA} + \dot{m}_{B,MA} - \sum_{segments} (\dot{m}_{w,seg,cond}),$$

where:

- $\frac{\partial \rho_{seg,MA}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,MA}}{\partial T}$  is the partial derivative of density with respect to temperature for the segment.
- $\frac{\partial \rho_{seg,MA}}{\partial x_w}$  is the partial derivative of density with respect to specific humidity for the segment.
- $\frac{\partial \rho_{seg,MA}}{\partial x_g}$  is the partial derivative of density with respect to trace gas mass fraction for the segment.
- $x_{w,seg,MA}$  is the specific humidity, that is, the water vapor mass fraction, for the segment.
- $x_{g,seg,MA}$  is the trace gas mass fraction for the segment.
- $V_{MA}$  is the total moist air volume.

The summation is over all segments.

**Note** Although the moist air flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{MA}$ . That is why  $p_{MA}$  is outside of the summation.

The energy conservation equation for each segment is

$$\left( \frac{dT_{seg,MA}}{dt} \frac{\partial u_{seg,MA}}{\partial T} + \frac{dx_{w,seg,MA}}{dt} \frac{\partial u_{seg,MA}}{\partial x_w} + \frac{dx_{g,seg,MA}}{dt} \frac{\partial u_{seg,MA}}{\partial x_g} \right) \frac{M_{MA}}{N} + u_{seg,MA} (\dot{m}_{seg,in,MA} - \dot{m}_{seg,out,MA}) \\ \Phi_{seg,in,MA} - \Phi_{seg,out,MA} + Q_{seg,MA} - \dot{m}_{w,seg,cond} h_{l,wall},$$

where:

- $\frac{\partial u_{seg,MA}}{\partial T}$  is the partial derivative of specific internal energy with respect to temperature for the segment.
- $\frac{\partial u_{seg,MA}}{\partial x_w}$  is the partial derivative of specific internal energy with respect to specific humidity for the segment.
- $\frac{\partial u_{seg,MA}}{\partial x_g}$  is the partial derivative of specific internal energy with respect to trace gas mass fraction for the segment.
- $u_{seg,2P}$  is the specific internal energy for the segment.
- $M_{MA}$  is the total moist air mass.
- $\dot{m}_{seg,in,MA}$  and  $\dot{m}_{seg,out,MA}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg,in,MA}$  and  $\Phi_{seg,out,MA}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A,MA}$  and  $\dot{m}_{B,MA}$ .

The water vapor mass conservation equation for each segment is

$$\frac{dx_{w,seg,MA}}{dt} \frac{M_{MA}}{N} + x_{w,seg,MA} (\dot{m}_{seg,in,MA} - \dot{m}_{seg,out,MA}) = \\ \dot{m}_{w,seg,in,MA} - \dot{m}_{w,seg,out,MA} - \dot{m}_{w,seg,cond},$$

where  $\dot{m}_{w,seg,in,MA}$  and  $\dot{m}_{w,seg,out,MA}$  are the water vapor mass flow rates into and out of the segment.

The trace gas mass conservation equation for each segment is

$$\frac{dx_{g,seg,MA}}{dt} \frac{M_{MA}}{N} + x_{g,seg,MA} (\dot{m}_{seg,in,MA} - \dot{m}_{seg,out,MA}) = \\ \dot{m}_{g,seg,in,MA} - \dot{m}_{g,seg,out,MA},$$

where  $\dot{m}_{g,seg,in,MA}$  and  $\dot{m}_{g,seg,out,MA}$  are the trace gas mass flow rates into and out of the segment.

## Ports

### Output

#### **Q1 — Rate of heat transfer to two-phase fluid, W**

physical signal

Rate of heat transfer to two-phase fluid, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to **On**, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

#### **Q2 — Rate of heat transfer to moist air, W**

physical signal

Rate of heat transfer to moist air, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to **On**, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

#### **W — Moist air condensation rate, kg/s**

physical signal

Water condensation rate in the moist air flow, returned as a physical signal. The condensate does not accumulate on the heat transfer surface.

### Conserving

#### **A1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **B1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **A2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

#### **B2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

## Parameters

### Configuration

#### Flow arrangement at nominal operating condition — Flow path alignment

Counter flow - Two-Phase Fluid 1 flows from A to B, Moist Air 2 flows from B to A (default) | Parallel flow - Both fluids flow from A to B | Cross flow - Both fluids flow from A to B

Flow path alignment between the heat exchanger sides at nominal operating condition. The available flow arrangements are:

- Counter flow - Two-Phase Fluid 1 flows from A to B, Moist Air 2 flows from B to A — The flows run parallel to each other, in the opposite directions.
- Parallel flow - Both fluids flow from A to B — The flows run in the same direction.
- Cross flow - Both fluids flow from A to B — The flows run perpendicular to each other.

The choice between parallel flow and counter flow affects how the block determines the size of the heat exchanger. Counter flow is the most effective, therefore it will need the smallest size to meet the specified performance. Conversely, parallel flow is the least effective, therefore it will need the biggest size to meet the specified performance.

Flow direction at nominal condition (from A to B, or from B to A) affects only the model initialization, in case if you set the **Initial condition specification** parameter to Same as nominal operating condition. If you set up different initial operating conditions, the flow directions can be different.

Once the size is determined, the choice between parallel and counter does not play a role in how the block calculates the heat transfer during simulation. Instead, the heat transfer depends on the flow directions during simulation. If you set the parameter to parallel flow but set up the model to run in counter flow (or the other way around), then the rate of heat transfer during simulation will not match the specified performance, even if the rest of the boundary conditions are the same.

If you set the parameter to cross flow, then the flow paths are modeled as perpendicular inside the heat exchanger, so the flow directions during simulation do not matter.

#### Wall thermal mass — Enable or disable effect of thermal mass on heat transfer surface

Off (default) | On

Enable or disable the effect of thermal mass on the heat transfer surface. Setting this parameter to On introduces additional dynamics to the simulation, so that it takes longer to reach steady state, but does not affect the results at steady-state simulation.

#### Wall mass — Mass of heat transfer surface

1 kg (default) | positive scalar

Mass of the heat transfer surface.

#### Dependencies

To enable this parameter, set **Wall thermal mass** to On.

#### Wall specific heat — Specific heat of heat transfer surface

490 J/(K\*kg) (default) | positive scalar

Specific heat of the heat transfer surface.

**Dependencies**

To enable this parameter, set **Wall thermal mass** to 0n.

**Cross-sectional area at port A1 — Flow area at port A1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **A1**.

**Cross-sectional area at port B1 — Flow area at port B1**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **B1**.

**Cross-sectional area at port A2 — Flow area at port A2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air port **A2**.

**Cross-sectional area at port B2 — Area normal to flow at port B2**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air port **B2**.

**Two-Phase Fluid 1****Nominal operating condition — Select whether nominal operating condition corresponds to condenser or evaporator**

Condenser - heat transfer from two-phase fluid to moist air (default) | Evaporator  
- heat transfer from moist air to two-phase fluid

Select the nominal operating condition:

- Condenser - heat transfer from two-phase fluid to moist air — The two-phase fluid is being cooled and the moist air is being heated.
- Evaporator - heat transfer from moist air to two-phase fluid — The moist air is being cooled and the two-phase fluid is being heated.

This choice relates only to specifying the nominal operating condition parameters. It does not mean that heat transfer can only happen in the specified direction during simulation.

**Nominal mass flow rate — Mass flow rate between two-phase ports during nominal operating condition**

0.001 kg/s (default) | positive scalar

Mass flow rate from port **A1** to port **B1** during the nominal operating condition.

**Nominal pressure drop — Pressure drop between two-phase ports during nominal operating condition**

0.01 MPa (default) | positive scalar

Pressure drop from port **A1** to port **B1** during the nominal operating condition.

**Pressure specification — Select method of pressure specification**

Inlet pressure (default) | Saturation pressure at specified condensing temperature  
| Saturation pressure at specified evaporating temperature

Select the method of pressure specification:

- Inlet pressure — Specify the nominal inlet pressure.
- Saturation pressure at specified condensing temperature — Specify the nominal condensing temperature. This option is available if you set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to moist air.
- Saturation pressure at specified evaporating temperature — Specify the nominal evaporating temperature. This option is available if you set **Nominal operating condition** to Evaporator - heat transfer from moist air to two-phase fluid.

**Nominal inlet pressure — Pressure at the two-phase fluid side inlet**

1 MPa (default) | positive scalar

Pressure at the inlet of the two-phase fluid side of the heat exchanger during nominal operating condition.

**Dependencies**

To enable this parameter, set **Pressure specification** to Inlet pressure.

**Nominal condensing temperature — Use nominal condensing temperature to specify pressure**

313.15 K (default) | positive scalar

Liquid saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal condensing temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to moist air and **Pressure specification** to Saturation pressure at specified condensing temperature.

**Nominal evaporating temperature — Use nominal evaporating temperature to specify pressure**

243.15 K (default) | positive scalar

Vapor saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal evaporating temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Nominal operating condition** to Evaporator - heat transfer from moist air to two-phase fluid and **Pressure specification** to Saturation pressure at specified evaporating temperature.

**Inlet condition specification — Select quantity to describe the inlet condition of the two-phase fluid**

Specific enthalpy (default) | Temperature | Vapor quality

Quantity used to describe the inlet condition of the fluid at the nominal operating condition: temperature, specific enthalpy, or vapor quality.

**Nominal inlet specific enthalpy — Specific enthalpy at the two-phase fluid side inlet**

440 kJ/kg (default) | positive scalar

Specific enthalpy at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Specific enthalpy.

**Nominal inlet temperature — Temperature at the two-phase fluid side inlet**

313.15 K (default) | positive scalar

Temperature at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Vapor quality at the two-phase fluid side inlet**

1 (default) | positive scalar

Vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Vapor quality.

**Heat transfer capacity specification — Select how to specify heat transfer capacity of the two-phase fluid**

Rate of heat transfer (default) | Outlet condition

Select whether to specify the performance of the heat exchanger at the nominal operating condition directly, by the rate of heat transfer, or indirectly, by the outlet condition.

**Nominal rate of heat transfer — Specify performance by rate of heat transfer**

0.1 kW (default) | positive scalar

Rate of heat transfer, depending on the nominal operating condition:

- If **Nominal operating condition** is Condenser - heat transfer from two-phase fluid to moist air, rate of heat transfer from the two-phase fluid to the moist air during the nominal operating condition.
- If **Nominal operating condition** is Evaporator - heat transfer from moist air to two-phase fluid, rate of heat transfer from the moist air to the two-phase fluid during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Rate of heat transfer.



**Outlet condition specification — Select quantity for outlet condition specification**

Specific enthalpy (default) | Subcooling | Superheating | Vapor quality

Select the quantity for outlet condition specification:

- Specific enthalpy — Specify the nominal specific enthalpy.
- Subcooling — Specify the nominal subcooling. This option is available if you set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to moist air.
- Superheating — Specify the nominal superheating. This option is available if you set **Nominal operating condition** to Evaporator - heat transfer from moist air to two-phase fluid.
- Vapor quality — Specify the nominal vapor quality.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Outlet condition.

**Nominal outlet specific enthalpy — Specific enthalpy at the two-phase fluid side outlet**

250 kJ/kg (default) | positive scalar | two-element vector

Specific enthalpy at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Specific enthalpy.

**Nominal subcooling — Degree of temperature below the liquid saturation temperature at the two-phase fluid side outlet**

5 deltaK (default) | positive scalar

Degree of temperature below the liquid saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Subcooling.

**Nominal superheating — Degree of temperature above the vapor saturation temperature at the two-phase fluid side outlet**

5 deltaK (default) | positive scalar

Degree of temperature above the vapor saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Superheating.

**Nominal outlet vapor quality — Vapor mass fraction at the two-phase fluid side outlet**

0 (default) | scalar in the range [0,1]

Two-phase fluid vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Vapor quality.

**Two-phase fluid volume — Total volume of two-phase fluid**

0.001 m<sup>3</sup> (default) | positive scalar

Total volume of two-phase fluid inside the heat exchanger.

**Initial condition specification — Select how to specify initial state of two-phase fluid**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of two-phase fluid:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial fluid energy specification — Initial state of the two-phase fluid**

Specific enthalpy (default) | Temperature | Vapor quality | Vapor void fraction | Specific internal energy

Quantity used to describe the initial state of the fluid.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- Temperature — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- Vapor quality — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- Vapor void fraction — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- Specific enthalpy — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- Specific internal energy — Specify the specific internal energy of the fluid. The block does not limit the initial state.

**Dependencies**

To enable this parameter, set **Initial condition specification** to Specify initial condition.

**Initial two-phase fluid pressure — Fluid pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Two-phase fluid pressure at the start of the simulation.

**Initial two-phase fluid specific enthalpy – Enthalpy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid specific enthalpy at the start of simulation. If the value is a scalar, then the initial specific enthalpy is assumed uniform. If the value is a two-element vector, then the initial specific enthalpy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

**Initial two-phase fluid temperature – Temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Two-phase fluid temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Temperature.

**Initial two-phase fluid vapor quality – Vapor mass fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor quality is assumed uniform. If the value is a two-element vector, then the initial vapor quality is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

**Initial two-phase fluid vapor void fraction – Vapor volume fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid vapor void fraction, defined as the volume fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor void fraction is assumed uniform. If the value is a two-element vector, then the initial vapor void fraction is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

**Initial two-phase fluid specific internal energy – Internal energy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid specific internal energy at the start of simulation. If the value is a scalar, then the initial specific internal energy is assumed uniform. If the value is a two-element vector, then the initial specific internal energy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

**Moist Air 2****Nominal mass flow rate – Mass flow rate between moist air ports during nominal operating condition**

0.1 kg/s (default) | positive scalar

Mass flow rate from port **A2** to port **B2** during the nominal operating condition.

**Nominal pressure drop – Pressure drop between moist air ports during nominal operating condition**

0.001 MPa (default) | positive scalar

Pressure drop from port **A2** to port **B2** during the nominal operating condition.

**Nominal inlet pressure – Pressure at the moist air side inlet**

0.101325 MPa (default) | positive scalar

Pressure at the inlet of the moist air side of the heat exchanger during nominal operating condition.

**Nominal inlet temperature – Temperature at the moist air side inlet**

293.15 K (default) | positive scalar

Temperature at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Inlet moisture specification – Quantity used to describe the moisture level at the moist air side inlet**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Select quantity used to describe the moisture level at the inlet during the nominal operating condition: relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

**Nominal inlet relative humidity – Relative humidity at the inlet**

0.5 (default) | scalar in the range [0,1]

Relative humidity at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Relative humidity.

**Nominal inlet specific humidity – Specific humidity at the inlet**

0.01 (default) | scalar in the range [0,1]

Specific humidity, defined as the mass fraction of water vapor in a moist air mixture, at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Specific humidity.

**Nominal inlet water vapor mole fraction – Mole fraction of water vapor at the inlet**

0.01 (default) | scalar in the range [0,1]

Mole fraction of water vapor in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Mole fraction.

**Nominal inlet humidity ratio – Humidity ratio at the inlet**

0.01 (default) | positive scalar in the range [0,1]

Humidity ratio, defined as the mass ratio of water vapor to dry air and trace gas, at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Humidity ratio.

**Inlet trace gas specification – Quantity used to describe trace gas level at the inlet**

Mass fraction (default) | Mole fraction

Select quantity used to describe the trace gas level at the inlet during the nominal operating condition: mass fraction or mole fraction.

**Nominal inlet trace gas mass fraction – Mass fraction of trace gas at the inlet**

0.001 (default) | scalar in the range [0,1]

Mass fraction of trace gas in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Inlet trace gas specification** to Mass fraction.

**Nominal inlet trace gas mole fraction – Mole fraction of trace gas at the inlet**

0.001 (default) | scalar in the range [0,1]

Mole fraction of trace gas in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Inlet trace gas specification** to Mole fraction.

**Moist air volume — Total volume of moist air in the heat exchanger**

0.1 m<sup>3</sup> (default) | positive scalar

Total volume of moist air in the heat exchanger.

**Initial condition specification — Select how to specify initial state of moist air**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of moist air:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial moist air pressure — Moist air pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Moist air pressure at the start of the simulation.

**Initial moist air temperature — Moist air temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Moist air temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Initial moisture specification — Quantity used to describe the initial moisture level**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Select quantity used to describe the initial moisture level: relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

**Initial moist air relative humidity — Relative humidity at the start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Moist air relative humidity at the start of simulation. If the value is a scalar, then the initial relative humidity is assumed uniform. If the value is a two-element vector, then the initial relative humidity is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Relative humidity.

**Initial moist air specific humidity — Specific humidity at the start of simulation**

0.01 (default) | scalar in the range [0,1] | two-element vector

Moist air specific humidity, defined as the mass fraction of water vapor in a moist air mixture, at the start of simulation. If the value is a scalar, then the initial specific humidity is assumed uniform. If the value is a two-element vector, then the initial specific humidity is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Specific humidity.

**Initial moist air water vapor mole fraction — Mole fraction of water vapor at the start of simulation**

0.01 (default) | scalar in the range [0,1] | two-element vector

Mole fraction of water vapor in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mole fraction is assumed uniform. If the value is a two-element vector, then the initial mole fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Mole fraction.

**Initial moist air humidity ratio — Humidity ratio at the start of simulation**

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Moist air humidity ratio, defined as the mass ratio of water vapor to dry air and trace gas, at the start of simulation. If the value is a scalar, then the initial humidity ratio is assumed uniform. If the value is a two-element vector, then the initial humidity ratio is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Humidity ratio.

**Initial trace gas specification — Quantity used to describe initial trace gas level**

Mass fraction (default) | Mole fraction

Select quantity used to describe the trace gas level at the start of simulation: mass fraction or mole fraction.

**Initial moist air trace gas mass fraction — Mass fraction of trace gas at the start of simulation**

0.001 (default) | scalar in the range [0,1] | two-element vector

Mass fraction of trace gas in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mass fraction is assumed uniform. If the value is a two-element vector, then the initial mass fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Initial trace gas specification** to Mass fraction.

**Initial moist air trace gas mole fraction — Mole fraction of trace gas at the start of simulation**

0.001 (default) | scalar in the range [0,1] | two-element vector

Mole fraction of trace gas in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mole fraction is assumed uniform. If the value is a two-element vector, then the initial mole fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

#### Dependencies

To enable this parameter, set **Initial trace gas specification** to Mole fraction.

#### Relative humidity at saturation – Relative humidity point of condensation

1 (default) | nonnegative scalar

Relative humidity point of condensation. Condensation occurs above this value. In most cases, this value is 1, that is, 100%. A value greater than 1 indicates a supersaturated vapor.

#### Correlation Coefficients

##### **a in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid liquid – Correlation coefficient for subcooled liquid in two-phase fluid**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for subcooled liquid in two-phase fluid. The default value is based on the Colburn equation.

##### **a in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid mixture – Correlation coefficient for liquid-vapor mixture in two-phase fluid**

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for liquid-vapor mixture in two-phase fluid. The default value is based on the Cavallini and Zecchin correlation.

##### **a in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid vapor – Correlation coefficient for superheated vapor in two-phase fluid**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for superheated vapor in two-phase fluid. The default value is based on the Colburn equation.

##### **b in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid – Reynolds number exponent in correlation for two-phase fluid**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

##### **c in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid – Prandtl number exponent in correlation for two-phase fluid**

0.33 (default) | positive scalar



Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air – Correlation coefficient for moist air**

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air – Reynolds number exponent in correlation for moist air**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air – Prandtl number exponent in correlation for moist air**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

## Version History

Introduced in R2021b

## References

- [1] *Ashrae Handbook: Fundamentals*. Atlanta: Ashrae, 2013.
- [2] Çengel, Yunus A. *Heat and Mass Transfer: A Practical Approach*. 3rd ed. McGraw-Hill Series in Mechanical Engineering. Boston: McGraw-Hill, 2007.
- [3] Mitchell, John W., and James E. Braun. *Principles of Heating, Ventilation, and Air Conditioning in Buildings*. Hoboken, NJ: Wiley, 2013.
- [4] Shah, R. K., and Dušan P. Sekulić. *Fundamentals of Heat Exchanger Design*. Hoboken, NJ: John Wiley & Sons, 2003.
- [5] Cavallini, Alberto, and Roberto Zecchin. "A DIMENSIONLESS CORRELATION FOR HEAT TRANSFER IN FORCED CONVECTION CONDENSATION." In *Proceeding of International Heat Transfer Conference 5*, 309-13. Tokyo, Japan: Begellhouse, 1974. <https://doi.org/10.1615/IHTC5.1220>.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

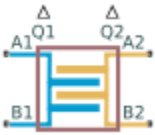
**See Also**

Condenser Evaporator (2P-MA) | System-Level Condenser Evaporator (2P-TL) | System-Level Heat Exchanger (2P-2P) | System-Level Heat Exchanger (TL-MA)

# System-Level Condenser Evaporator (2P-TL)

Heat exchanger between two-phase fluid and thermal liquid networks, with model based on performance data

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



## Description

The System-Level Condenser Evaporator (2P-TL) block models a heat exchanger between a two-phase fluid network and a thermal liquid network.

The block can act as a condenser or as an evaporator in a refrigeration system, depending on the direction of heat transfer. The block model is based on performance data from the heat exchanger datasheet, rather than on the detailed geometry of the exchanger, and therefore lets you easily adjust the size and performance of the heat exchanger during design iterations, or model heat exchangers with uncommon geometries. You can also use this block to model heat exchangers with a certain level of performance at an early design stage, when detailed geometry data is not yet available.

You parameterize the block by the nominal operating condition. The heat exchanger is sized to match the specified performance at the nominal operating condition at steady state.

The Two-Phase Fluid 1 side approximates the liquid zone, mixture zone, and vapor zone based on the change in enthalpy along the flow path.

This block is similar to the Condenser Evaporator (TL-2P) block but uses a different parameterization model. The table provides a comparison of the two blocks, to help you choose the right block for your application.

Condenser Evaporator (TL-2P)	System-Level Condenser Evaporator (2P-TL)
Block parameters are based on the heat exchanger geometry	Block parameters are based on performance and operating conditions
Heat exchanger geometry may be limited by the available geometry parameter options	Model is independent of the specific heat exchanger geometry
You can adjust the block for different performance requirements by tuning geometry parameters, such as fin sizes and tube lengths	You can adjust the block for different performance requirements by directly specifying the desired heat and mass flow rates
Lets you select between parallel, counter, or cross flow configurations	Lets you select between parallel, counter, or cross flow arrangement at nominal operating conditions, to help with sizing

Condenser Evaporator (TL-2P)	System-Level Condenser Evaporator (2P-TL)
Predictively accurate results over a wide range of operating conditions, subject to the applicability of the E-NTU equations and the heat transfer coefficient correlations	Very accurate results around the specified operating condition; accuracy may decrease far away from the specified operating conditions
Heat transfer calculations account for the variation of temperature along the flow path by using the E-NTU model	Heat transfer calculations approximate the variation of temperature along the flow path by dividing it into three segments
Accounts for different fluid properties and heat transfer coefficients for subcooled liquid, liquid-vapor mixture, and superheated vapor	Accounts for different fluid properties and heat transfer coefficients for subcooled liquid, liquid-vapor mixture, and superheated vapor
Keeps track of variable zone length fractions for subcooled liquid, liquid-vapor mixture, and superheated vapor regions based on the geometry	Approximates the effect of subcooled liquid, liquid-vapor mixture, and superheated vapor regions using weighting factors based on the difference in enthalpy between inlet and outlet
Does not model the wall thermal mass; you can approximate the effect by connecting a pipe block with a thermal mass downstream	Includes an option to model the wall thermal mass

### Heat Transfer

The two-phase fluid flow and the thermal liquid flow are each divided into three segments of equal size. Heat transfer between the fluids is calculated in each segment. For simplicity, the equation for one segment is shown here.

If the wall thermal mass is off, then the heat balance in the heat exchanger is

$$Q_{seg, 2P} + Q_{seg, TL} = 0,$$

where:

- $Q_{seg, 2P}$  is the heat flow rate from the wall (that is, the heat transfer surface) to the two-phase fluid in the segment.
- $Q_{seg, TL}$  is the heat flow rate from the wall to the thermal liquid in the segment.

If the wall thermal mass is on, then the heat balance in the heat exchanger is

$$Q_{seg, 2P} + Q_{seg, TL} = - \frac{M_{wall} c_{pwall}}{N} \frac{dT_{seg, wall}}{dt},$$

where:

- $M_{wall}$  is the mass of the wall.
- $c_{pwall}$  is the specific heat of the wall.
- $N = 3$  is the number of segments.
- $T_{seg, wall}$  is the average wall temperature in the segment.
- $t$  is time.

The heat flow rate from the wall to the two-phase fluid in the segment is

$$Q_{seg, 2P} = UA_{seg, 2P}(T_{seg, wall} - T_{seg, 2P}),$$

where:

- $UA_{seg,2P}$  is the weighted-average heat transfer conductance for the two-phase fluid in the segment.
- $T_{seg,2P}$  is the weighted-average fluid temperature for the two-phase fluid in the segment.

The heat flow rate from the wall to the thermal liquid in the segment is

$$Q_{seg,TL} = UA_{seg,TL}(T_{seg,wall} - T_{seg,TL}),$$

where:

- $UA_{seg,TL}$  is the heat transfer conductance for the thermal liquid in the segment.
- $T_{seg,TL}$  is the average liquid temperature in the segment.

### Two-Phase Fluid Heat Transfer Correlation

If the segment is subcooled liquid, then the heat transfer conductance is

$$UA_{seg,L,2P} = a_{L,2P}(Re_{seg,L,2P})^{b_{2P}}(Pr_{seg,L,2P})^{c_{2P}}k_{seg,L,2P}\frac{G_{2P}}{N},$$

where:

- $a_{L,2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,L,2P}$  is the average liquid Reynolds number for the segment.
- $Pr_{seg,L,2P}$  is the average liquid Prandtl number for the segment.
- $k_{seg,L,2P}$  is the average liquid thermal conductivity for the segment.
- $G_{2P}$  is the geometry scale factor for the two-phase fluid side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average liquid Reynolds number is

$$Re_{seg,L,2P} = \frac{\dot{m}_{seg,2P}D_{ref,2P}}{\mu_{seg,L,2P}S_{ref,2P}},$$

where:

- $\dot{m}_{seg,2P}$  is the mass flow rate through the segment.
- $\mu_{seg,L,2P}$  is the average liquid dynamic viscosity for the segment.
- $D_{ref,2P}$  is an arbitrary reference diameter.
- $S_{ref,2P}$  is an arbitrary reference flow area.

---

**Note** The  $D_{ref,2P}$  and  $S_{ref,2P}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,L,2P}$  nondimensional. The values of  $D_{ref,2P}$  and  $S_{ref,2P}$  are arbitrary because the  $G_{2P}$  calculation overrides these values.

---

Similarly, if the segment is superheated vapor, then the heat transfer conductance is

$$UA_{seg, V, 2P} = a_{V, 2P} (Re_{seg, V, 2P})^{b_{2P}} (Pr_{seg, V, 2P})^{c_{2P}} k_{seg, V, 2P} \frac{G_{2P}}{N},$$

where:

- $a_{V, 2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg, V, 2P}$  is the average vapor Reynolds number for the segment.
- $Pr_{seg, V, 2P}$  is the average vapor Prandtl number for the segment.
- $k_{seg, V, 2P}$  is the average vapor thermal conductivity for the segment.

The average vapor Reynolds number is

$$Re_{seg, V, 2P} = \frac{\dot{m}_{seg, 2P} D_{ref, 2P}}{\mu_{seg, V, 2P} S_{ref, 2P}},$$

where  $\mu_{seg, V, 2P}$  is the average vapor dynamic viscosity for the segment.

If the segment is liquid-vapor mixture, then the heat transfer conductance is

$$UA_{seg, M, 2P} = a_{M, 2P} (Re_{seg, SL, 2P})^{b_{2P}} CZ (Pr_{seg, SL, 2P})^{c_{2P}} k_{seg, SL, 2P} \frac{G_{2P}}{N},$$

where:

- $a_{M, 2P}$ ,  $b_{2P}$ , and  $c_{2P}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg, SL, 2P}$  is the saturated liquid Reynolds number for the segment.
- $Pr_{seg, SL, 2P}$  is the saturated liquid Prandtl number for the segment.
- $k_{seg, SL, 2P}$  is the saturated liquid thermal conductivity for the segment.
- $CZ$  is the Cavallini and Zecchin term.

The saturated liquid Reynolds number is

$$Re_{seg, SL, 2P} = \frac{\dot{m}_{seg, 2P} D_{ref, 2P}}{\mu_{seg, SL, 2P} S_{ref, 2P}},$$

where  $\mu_{seg, SL, 2P}$  is the saturated liquid dynamic viscosity for the segment.

The Cavallini and Zecchin term is

$$CZ = \frac{\left( \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, out, 2P} + 1) \right)^{1 + b_{2P}} - \left( \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, in, 2P} + 1) \right)^{1 + b_{2P}}}{(1 + b_{2P}) \left( \sqrt{\frac{\nu_{seg, SV, 2P}}{\nu_{seg, SL, 2P}}} - 1 \right) (x_{seg, out, 2P} - x_{seg, in, 2P})},$$

where:

- $\nu_{seg, SL, 2P}$  is the saturated liquid specific volume for the segment.
- $\nu_{seg, SV, 2P}$  is the saturated vapor specific volume for the segment.
- $x_{seg, in, 2P}$  is the vapor quality at the segment inlet.

- $x_{\text{seg,out},2P}$  is the vapor quality at the segment outlet.

The expression is based on the work of Cavallini and Zecchin [5], which derives a heat transfer coefficient correlation at a local vapor quality  $x$ . Equations for the liquid-vapor mixture are obtained by averaging Cavallini and Zecchin's correlation over the segment from  $x_{\text{seg,in},2P}$  to  $x_{\text{seg,out},2P}$ .

### Two-Phase Fluid Weighted Average

The two-phase fluid flow through a segment may not be entirely represented as either subcooled liquid, superheated vapor, or liquid-vapor mixture. Instead, each segment may consist of a combination of these. The block approximates this condition by computing weighting factors ( $w_L$ ,  $w_V$ , and  $w_M$ ) based on the change in specific enthalpy across the segment and the saturated liquid and vapor specific enthalpies. The block assumes that the specific enthalpy across the segment varies piecewise linearly from inlet to outlet, with the breakpoints corresponding to the saturation boundaries for liquid and vapor. The zone with a larger heat transfer coefficient has a steeper slope than the zone with a lower heat transfer coefficient.

$$w_L = \frac{\Delta_L}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_V = \frac{\Delta_V}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_M = 1 - w_L - w_V$$

$$\Delta_L = |\min(h_{\text{seg,out},2P}, h_{\text{seg,SL},2P}) - \min(h_{\text{seg,in},2P}, h_{\text{seg,SL},2P})| \cdot UA_{\text{seg},M,2P} \cdot UA_{\text{seg},V,2P}$$

$$\Delta_M = |\min(\max(h_{\text{seg,out},2P}, h_{\text{seg,SL},2P}), h_{\text{seg,SV},2P}) - \min(\max(h_{\text{seg,in},2P}, h_{\text{seg,SL},2P}), h_{\text{seg,SV},2P})| \cdot UA_{\text{seg},L,2P} \cdot U$$

$$\Delta_V = |\max(h_{\text{seg,out},2P}, h_{\text{seg,SV},2P}) - \max(h_{\text{seg,in},2P}, h_{\text{seg,SV},2P})| \cdot UA_{\text{seg},L,2P} \cdot UA_{\text{seg},M,2P}$$

where:

- $h_{\text{seg,in},2P}$  is the specific enthalpy at the segment inlet.
- $h_{\text{seg,out},2P}$  is the specific enthalpy at the segment outlet.
- $h_{\text{seg,SL},2P}$  is the saturated liquid specific enthalpy for the segment.
- $h_{\text{seg,SV},2P}$  is the saturated vapor specific enthalpy for the segment.

The weighted-average two-phase fluid heat transfer conductance for the segment is therefore

$$UA_{\text{seg},2P} = w_L(UA_{\text{seg},L,2P}) + w_V(UA_{\text{seg},V,2P}) + w_M(UA_{\text{seg},M,2P}).$$

The weighted-average fluid temperature for the segment is

$$T_{\text{seg},2P} = \frac{w_L(UA_{\text{seg},L,2P})T_{\text{seg},L,2P} + w_V(UA_{\text{seg},V,2P})T_{\text{seg},V,2P} + w_M(UA_{\text{seg},M,2P})T_{\text{seg},M,2P}}{UA_{\text{seg},2P}},$$

where:

- $T_{\text{seg},L,2P}$  is the average liquid temperature for the segment.
- $T_{\text{seg},V,2P}$  is the average vapor temperature for the segment.
- $T_{\text{seg},M,2P}$  is the average mixture temperature for the segment, which is the saturated liquid temperature.

### Thermal Liquid Heat Transfer Correlation

The heat transfer conductance is

$$UA_{seg, TL} = a_{TL} (Re_{seg, TL})^{b_{TL}} (Pr_{seg, TL})^{c_{TL}} k_{seg, TL} \frac{G_{TL}}{N},$$

where:

- $a_{TL}$ ,  $b_{TL}$ , and  $c_{TL}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg, TL}$  is the average Reynolds number for the segment.
- $Pr_{seg, TL}$  is the average Prandtl number for the segment.
- $k_{seg, TL}$  is the average thermal conductivity for the segment.
- $G_{TL}$  is the geometry scale factor for the thermal liquid side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average Reynolds number is

$$Re_{seg, TL} = \frac{\dot{m}_{seg, TL} D_{ref, TL}}{\mu_{seg, TL} S_{ref, TL}},$$

where:

- $\dot{m}_{seg, TL}$  is the mass flow rate through the segment.
- $\mu_{seg, TL}$  is the average dynamic viscosity for the segment.
- $D_{ref, TL}$  is an arbitrary reference diameter.
- $S_{ref, TL}$  is an arbitrary reference flow area.

---

**Note** The  $D_{ref, TL}$  and  $S_{ref, TL}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg, TL}$  nondimensional. The values of  $D_{ref, TL}$  and  $S_{ref, TL}$  are arbitrary because the  $G_{TL}$  calculation overrides these values.

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### Pressure Loss

The pressure losses on the two-phase fluid side are

$$p_{A, 2P} - p_{2P} = \frac{K_{2P} \dot{m}_{A, 2P} \sqrt{\dot{m}_{A, 2P}^2 + \dot{m}_{thres, 2P}^2}}{2 \rho_{avg, 2P}}$$

$$p_{B, 2P} - p_{2P} = \frac{K_{2P} \dot{m}_{B, 2P} \sqrt{\dot{m}_{B, 2P}^2 + \dot{m}_{thres, 2P}^2}}{2 \rho_{avg, 2P}}$$

where:

- $p_{A, 2P}$  and  $p_{B, 2P}$  are the pressures at ports **A1** and **B1**, respectively.
- $p_{2P}$  is internal two-phase fluid pressure at which the heat transfer is calculated.
- $\dot{m}_{A, 2P}$  and  $\dot{m}_{B, 2P}$  are the mass flow rates into ports **A1** and **B1**, respectively.



- $\rho_{avg,2P}$  is the average two-phase fluid density over all segments.
- $\dot{m}_{thres,2P}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{2P}$ , so that  $p_{A,2P} - p_{B,2P}$  matches the nominal pressure loss at the nominal mass flow rate.

The pressure losses on the thermal liquid side are

$$p_{A,TL} - p_{TL} = \frac{K_{TL} \dot{m}_{A,TL} \sqrt{\dot{m}_{A,TL}^2 + \dot{m}_{thres,TL}^2}}{2 \rho_{avg,2P}}$$

$$p_{B,TL} - p_{TL} = \frac{K_{TL} \dot{m}_{B,TL} \sqrt{\dot{m}_{B,TL}^2 + \dot{m}_{thres,TL}^2}}{2 \rho_{avg,TL}}$$

where:

- $p_{A,TL}$  and  $p_{B,TL}$  are the pressures at ports **A2** and **B2**, respectively.
- $p_{TL}$  is internal thermal liquid pressure at which the heat transfer is calculated.
- $\dot{m}_{A,TL}$  and  $\dot{m}_{B,TL}$  are the mass flow rates into ports **A2** and **B2**, respectively.
- $\rho_{avg,TL}$  is the average thermal liquid density over all segments.
- $\dot{m}_{thres,TL}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{TL}$ , so that  $p_{A,TL} - p_{B,TL}$  matches the nominal pressure loss at the nominal mass flow rate.

### Two-Phase Fluid Mass and Energy Conservation

The mass conservation equation for the overall two-phase fluid flow is

$$\left( \frac{dp_{2P}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,2P}}{\partial p} \right) + \sum_{segments} \left( \frac{du_{seg,2P}}{dt} \frac{\partial \rho_{seg,2P}}{\partial u} \right) \right) \frac{V_{2P}}{N} = \dot{m}_{A,2P} + \dot{m}_{B,2P},$$

where:

- $\frac{\partial \rho_{seg,2P}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,2P}}{\partial u}$  is the partial derivative of density with respect to specific internal energy for the segment.
- $u_{seg,2P}$  is the specific internal energy for the segment.
- $V_{2P}$  is the total two-phase fluid volume.

The summation is over all segments.

---

**Note** Although the two-phase fluid flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{2P}$ . That is why  $p_{2P}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\frac{du_{seg,2P} M_{2P}}{dt} \frac{M_{2P}}{N} + u_{seg,2P} (\dot{m}_{seg,in,2P} - \dot{m}_{seg,out,2P}) = \Phi_{seg,in,2P} - \Phi_{seg,out,2P} + Q_{seg,2P},$$

where:

- $M_{2P}$  is the total two-phase fluid mass.
- $\dot{m}_{seg,in,2P}$  and  $\dot{m}_{seg,out,2P}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg,in,2P}$  and  $\Phi_{seg,out,2P}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A,2P}$  and  $\dot{m}_{B,2P}$ .

### Thermal Liquid Mass and Energy Conservation

The mass conservation for the overall thermal liquid flow is

$$\left( \frac{dp_{TL}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,TL}}{\partial p} \right) + \sum_{segments} \left( \frac{dT_{seg,TL}}{dt} \frac{\partial \rho_{seg,TL}}{\partial T} \right) \right) \frac{V_{TL}}{N} = \dot{m}_{A,TL} + \dot{m}_{B,TL},$$

where:

- $\frac{\partial \rho_{seg,TL}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,TL}}{\partial T}$  is the partial derivative of density with respect to temperature for the segment.
- $T_{seg,TL}$  is the temperature for the segment.
- $V_{TL}$  is the total thermal liquid volume.

The summation is over all segments.

---

**Note** Although the thermal liquid flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{TL}$ . That is why  $p_{TL}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\left( \frac{dp_{TL}}{dt} \frac{\partial u_{seg,TL}}{\partial p} + \frac{dT_{seg,TL}}{dt} \frac{\partial u_{seg,TL}}{\partial T} \right) \frac{M_{TL}}{N} + u_{seg,TL} (\dot{m}_{seg,in,TL} - \dot{m}_{seg,out,TL}) = \Phi_{seg,in,TL} - \Phi_{seg,out,TL} + Q_{seg,TL},$$

where:

- $\frac{\partial u_{seg,TL}}{\partial p}$  is the partial derivative of specific internal energy with respect to pressure for the segment.
- $\frac{\partial u_{seg,TL}}{\partial T}$  is the partial derivative of specific internal energy with respect to temperature for the segment.

- $M_{TL}$  is the total thermal liquid mass.
- $\dot{m}_{seg, in, TL}$  and  $\dot{m}_{seg, out, TL}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg, in, TL}$  and  $\Phi_{seg, out, TL}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A, TL}$  and  $\dot{m}_{B, TL}$ .

## Ports

### Output

#### **Q1 — Rate of heat transfer to two-phase fluid, W**

physical signal

Rate of heat transfer to two-phase fluid, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to 0n, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

#### **Q2 — Rate of heat transfer to thermal liquid, W**

physical signal

Rate of heat transfer to thermal liquid, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to 0n, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

### Conserving

#### **A1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **B1 — Two-phase fluid port**

two-phase fluid

Inlet or outlet port associated with the two-phase fluid.

#### **A2 — Thermal liquid port**

thermal liquid

Inlet or outlet port associated with the thermal liquid.

#### **B2 — Thermal liquid port**

thermal liquid

Inlet or outlet port associated with the thermal liquid.

## Parameters

### Configuration

#### Flow arrangement at nominal operating condition — Flow path alignment

Counter flow - Two-Phase Fluid 1 flows from A to B, Thermal Liquid 2 flows from B to A (default) | Parallel flow - Both fluids flow from A to B | Cross flow - Both fluids flow from A to B

Flow path alignment between the heat exchanger sides at nominal operating condition. The available flow arrangements are:

- Counter flow - Two-Phase Fluid 1 flows from A to B, Thermal Liquid 2 flows from B to A — The flows run parallel to each other, in the opposite directions.
- Parallel flow - Both fluids flow from A to B — The flows run in the same direction.
- Cross flow - Both fluids flow from A to B — The flows run perpendicular to each other.

The choice between parallel flow and counter flow affects how the block determines the size of the heat exchanger. Counter flow is the most effective, therefore it will need the smallest size to meet the specified performance. Conversely, parallel flow is the least effective, therefore it will need the biggest size to meet the specified performance.

Flow direction at nominal condition (from A to B, or from B to A) affects only the model initialization, in case if you set the **Initial condition specification** parameter to Same as nominal operating condition. If you set up different initial operating conditions, the flow directions can be different.

Once the size is determined, the choice between parallel and counter does not play a role in how the block calculates the heat transfer during simulation. Instead, the heat transfer depends on the flow directions during simulation. If you set the parameter to parallel flow but set up the model to run in counter flow (or the other way around), then the rate of heat transfer during simulation will not match the specified performance, even if the rest of the boundary conditions are the same.

If you set the parameter to cross flow, then the flow paths are modeled as perpendicular inside the heat exchanger, so the flow directions during simulation do not matter.

#### Wall thermal mass — Enable or disable effect of thermal mass on heat transfer surface

Off (default) | On

Enable or disable the effect of thermal mass on the heat transfer surface. Setting this parameter to On introduces additional dynamics to the simulation, so that it takes longer to reach steady state, but does not affect the results at steady-state simulation.

#### Wall mass — Mass of heat transfer surface

1 kg (default) | positive scalar

Mass of the heat transfer surface.

#### Dependencies

To enable this parameter, set **Wall thermal mass** to On.

#### Wall specific heat — Specific heat of heat transfer surface

490 J/(K\*kg) (default) | positive scalar

Specific heat of the heat transfer surface.

#### Dependencies

To enable this parameter, set **Wall thermal mass** to 0n.

#### Cross-sectional area at port A1 — Flow area at port A1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **A1**.

#### Cross-sectional area at port B1 — Flow area at port B1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid port **B1**.

#### Cross-sectional area at port A2 — Flow area at port A2

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **A2**.

#### Cross-sectional area at port B2 — Area normal to flow at port B2

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **B2**.

#### Two-Phase Fluid 1

#### Nominal operating condition — Select whether nominal operating condition corresponds to condenser or evaporator

Condenser - heat transfer from two-phase fluid to thermal liquid (default) |  
Evaporator - heat transfer from thermal liquid to two-phase fluid

Select the nominal operating condition:

- Condenser - heat transfer from two-phase fluid to thermal liquid — The two-phase fluid is being cooled and the thermal liquid is being heated.
- Evaporator - heat transfer from thermal liquid to two-phase fluid — The thermal liquid is being cooled and the two-phase fluid is being heated.

This choice relates only to specifying the nominal operating condition parameters. It does not mean that heat transfer can only happen in the specified direction during simulation.

#### Nominal mass flow rate — Mass flow rate between two-phase ports during nominal operating condition

0.001 kg/s (default) | positive scalar

Mass flow rate from port **A1** to port **B1** during the nominal operating condition.

#### Nominal pressure drop — Pressure drop between two-phase ports during nominal operating condition

0.01 MPa (default) | positive scalar

Pressure drop from port **A1** to port **B1** during the nominal operating condition.

**Pressure specification — Select method of pressure specification**

Inlet pressure (default) | Saturation pressure at specified condensing temperature  
| Saturation pressure at specified evaporating temperature

Select the method of pressure specification:

- Inlet pressure — Specify the nominal inlet pressure.
- Saturation pressure at specified condensing temperature — Specify the nominal condensing temperature. This option is available if you set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to thermal liquid.
- Saturation pressure at specified evaporating temperature — Specify the nominal evaporating temperature. This option is available if you set **Nominal operating condition** to Evaporator - heat transfer from thermal liquid to two-phase fluid.

**Nominal inlet pressure — Pressure at the two-phase fluid side inlet**

1 MPa (default) | positive scalar

Pressure at the inlet of the two-phase fluid side of the heat exchanger during nominal operating condition.

**Dependencies**

To enable this parameter, set **Pressure specification** to Inlet pressure.

**Nominal condensing temperature — Use nominal condensing temperature to specify pressure**

313.15 K (default) | positive scalar

Liquid saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal condensing temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to thermal liquid and **Pressure specification** to Saturation pressure at specified condensing temperature.

**Nominal evaporating temperature — Use nominal evaporating temperature to specify pressure**

243.15 K (default) | positive scalar

Vapor saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal evaporating temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Nominal operating condition** to Evaporator - heat transfer from thermal liquid to two-phase fluid and **Pressure specification** to Saturation pressure at specified evaporating temperature.

**Inlet condition specification — Select quantity to describe the inlet condition of the two-phase fluid**

Specific enthalpy (default) | Temperature | Vapor quality

Quantity used to describe the inlet condition of the fluid at the nominal operating condition: temperature, specific enthalpy, or vapor quality.

**Nominal inlet specific enthalpy — Specific enthalpy at the two-phase fluid side inlet**

440 kJ/kg (default) | positive scalar

Specific enthalpy at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Specific enthalpy.

**Nominal inlet temperature — Temperature at the two-phase fluid side inlet**

313.15 K (default) | positive scalar

Temperature at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Vapor quality at the two-phase fluid side inlet**

1 (default) | positive scalar

Vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the inlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Vapor quality.

**Heat transfer capacity specification — Select how to specify heat transfer capacity of the two-phase fluid**

Rate of heat transfer (default) | Outlet condition

Select whether to specify the performance of the heat exchanger at the nominal operating condition directly, by the rate of heat transfer, or indirectly, by the outlet condition.

**Nominal rate of heat transfer — Specify performance by rate of heat transfer**

0.1 kW (default) | positive scalar

Rate of heat transfer, depending on the nominal operating condition:

- If **Nominal operating condition** is Condenser - heat transfer from two-phase fluid to thermal liquid, rate of heat transfer from the two-phase fluid to the thermal liquid during the nominal operating condition.
- If **Nominal operating condition** is Evaporator - heat transfer from thermal liquid to two-phase fluid, rate of heat transfer from the thermal liquid to the two-phase fluid during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Rate of heat transfer.

**Outlet condition specification — Select quantity for outlet condition specification**

Specific enthalpy (default) | Subcooling | Superheating | Vapor quality

Select the quantity for outlet condition specification:

- Specific enthalpy — Specify the nominal specific enthalpy.
- Subcooling — Specify the nominal subcooling. This option is available if you set **Nominal operating condition** to Condenser - heat transfer from two-phase fluid to thermal liquid.
- Superheating — Specify the nominal superheating. This option is available if you set **Nominal operating condition** to Evaporator - heat transfer from thermal liquid to two-phase fluid.
- Vapor quality — Specify the nominal vapor quality.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Outlet condition.

**Nominal outlet specific enthalpy — Specific enthalpy at the two-phase fluid side outlet**

250 kJ/kg (default) | positive scalar | two-element vector

Specific enthalpy at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Specific enthalpy.

**Nominal subcooling — Degree of temperature below the liquid saturation temperature at the two-phase fluid side outlet**

5 deltaK (default) | positive scalar

Degree of temperature below the liquid saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Subcooling.

**Nominal superheating — Degree of temperature above the vapor saturation temperature at the two-phase fluid side outlet**

5 deltaK (default) | positive scalar

Degree of temperature above the vapor saturation temperature at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Superheating.

**Nominal outlet vapor quality — Vapor mass fraction at the two-phase fluid side outlet**

0 (default) | scalar in the range [0,1]

Two-phase fluid vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the outlet of the two-phase fluid side of the heat exchanger during the nominal operating condition.



**Dependencies**

To enable this parameter, set **Outlet condition specification** to Vapor quality.

**Two-phase fluid volume — Total volume of two-phase fluid**

0.001 m<sup>3</sup> (default) | positive scalar

Total volume of two-phase fluid inside the heat exchanger.

**Initial condition specification — Select how to specify initial state of two-phase fluid**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of two-phase fluid:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial fluid energy specification — Initial state of the two-phase fluid**

Specific enthalpy (default) | Temperature | Vapor quality | Vapor void fraction | Specific internal energy

Quantity used to describe the initial state of the fluid.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- Temperature — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- Vapor quality — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- Vapor void fraction — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- Specific enthalpy — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- Specific internal energy — Specify the specific internal energy of the fluid. The block does not limit the initial state.

**Dependencies**

To enable this parameter, set **Initial condition specification** to Specify initial condition.

**Initial two-phase fluid pressure — Fluid pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Two-phase fluid pressure at the start of the simulation.

**Initial two-phase fluid specific enthalpy — Enthalpy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid specific enthalpy at the start of simulation. If the value is a scalar, then the initial specific enthalpy is assumed uniform. If the value is a two-element vector, then the initial specific enthalpy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

**Initial two-phase fluid temperature — Temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Two-phase fluid temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Temperature.

**Initial two-phase fluid vapor quality — Vapor mass fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor quality is assumed uniform. If the value is a two-element vector, then the initial vapor quality is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

**Initial two-phase fluid vapor void fraction — Vapor volume fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid vapor void fraction, defined as the volume fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor void fraction is assumed uniform. If the value is a two-element vector, then the initial vapor void fraction is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

**Initial two-phase fluid specific internal energy — Internal energy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid specific internal energy at the start of simulation. If the value is a scalar, then the initial specific internal energy is assumed uniform. If the value is a two-element vector, then the initial specific internal energy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

**Thermal Liquid 2****Nominal mass flow rate — Mass flow rate between thermal liquid ports during nominal operating condition**

0.1 kg/s (default) | positive scalar

Mass flow rate from port **A2** to port **B2** during the nominal operating condition.

**Nominal pressure drop — Pressure drop between thermal liquid ports during nominal operating condition**

0.01 MPa (default) | positive scalar

Pressure drop from port **A2** to port **B2** during the nominal operating condition.

**Nominal inlet pressure — Pressure at the thermal liquid side inlet**

0.101325 MPa (default) | positive scalar

Pressure at the inlet of the thermal liquid side of the heat exchanger during nominal operating condition.

**Nominal inlet temperature — Temperature at the thermal liquid side inlet**

293.15 K (default) | positive scalar

Temperature at the inlet of the thermal liquid side of the heat exchanger during the nominal operating condition.

**Thermal liquid volume — Total volume of thermal liquid in the heat exchanger**0.001 m<sup>3</sup> (default) | positive scalar

Total volume of thermal liquid in the heat exchanger.

**Initial condition specification — Select how to specify initial state of thermal liquid**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of thermal liquid:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial thermal liquid pressure — Thermal liquid pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Thermal liquid pressure at the start of the simulation.

**Initial thermal liquid temperature — Thermal liquid temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Thermal liquid temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Correlation Coefficients**

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid liquid — Correlation coefficient for subcooled liquid in two-phase fluid**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for subcooled liquid in two-phase fluid. The default value is based on the Colburn equation.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid mixture — Correlation coefficient for liquid-vapor mixture in two-phase fluid**

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for liquid-vapor mixture in two-phase fluid. The default value is based on the Cavallini and Zecchin correlation.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid vapor — Correlation coefficient for superheated vapor in two-phase fluid**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for superheated vapor in two-phase fluid. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid — Reynolds number exponent in correlation for two-phase fluid**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid — Prandtl number exponent in correlation for two-phase fluid**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid — Correlation coefficient for thermal liquid**

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid – Reynolds number exponent in correlation for thermal liquid**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid. The default value is based on the Colburn equation.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid – Prandtl number exponent in correlation for thermal liquid**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid. The default value is based on the Colburn equation.

## Version History

Introduced in R2022a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

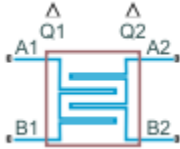
## See Also

System-Level Condenser Evaporator (2P-MA) | System-Level Heat Exchanger (2P-2P) | System-Level Heat Exchanger (TL-MA)

## System-Level Heat Exchanger (2P-2P)

Heat exchanger between two two-phase fluid networks, with model based on performance data

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



### Description

The System-Level Heat Exchanger (2P-2P) block models a heat exchanger between two distinct two-phase fluid networks. Each network has its own set of fluid properties.

The block model is based on performance data from the heat exchanger datasheet, rather than on the detailed geometry of the exchanger, and therefore you can use this block when geometry data is unavailable. Either or both sides of the heat exchanger can condense or vaporize fluid as a result of the heat exchange. You can also use this block as an internal heat exchanger in a refrigeration system. An internal heat exchanger improves refrigeration system efficiency by providing additional heat exchange between the outlet of the condenser and the outlet of the evaporator.

You parameterize the block by the nominal operating condition. The heat exchanger is sized to match the specified performance at the nominal operating condition at steady state.

Each side of the heat exchanger approximates the liquid zone, mixture zone, and vapor zone based on the change in enthalpy along the flow path.

### Heat Transfer

The two-phase fluid 1 flow and the two-phase fluid 2 flow are each divided into three segments of equal size. Heat transfer between the fluids is calculated in each segment. For simplicity, the equation for one segment is shown here.

If the wall thermal mass is off, then the heat balance in the heat exchanger is

$$Q_{seg,2P1} + Q_{seg,2P2} = 0,$$

where:

- $Q_{seg,2P1}$  is the heat flow rate from the wall (that is, the heat transfer surface) to the two-phase fluid 1 in the segment.
- $Q_{seg,2P2}$  is the heat flow rate from the wall to the two-phase fluid 2 in the segment.

If the wall thermal mass is on, then the heat balance in the heat exchanger is

$$Q_{seg,2P1} + Q_{seg,2P2} = - \frac{M_{wall} c_{pwall}}{N} \frac{dT_{seg,wall}}{dt},$$

where:

- $M_{\text{wall}}$  is the mass of the wall.
- $c_{\text{pwall}}$  is the specific heat of the wall.
- $N = 3$  is the number of segments.
- $T_{\text{seg,wall}}$  is the average wall temperature in the segment.
- $t$  is time.

The heat flow rate from the wall to the two-phase fluid 1 in the segment is

$$Q_{\text{seg}, 2P1} = UA_{\text{seg}, 2P1}(T_{\text{seg}, \text{wall}} - T_{\text{seg}, 2P1}),$$

where:

- $UA_{\text{seg}, 2P1}$  is the weighted-average heat transfer conductance for the two-phase fluid 1 in the segment.
- $T_{\text{seg}, 2P1}$  is the weighted-average fluid temperature for the two-phase fluid 1 in the segment.

The heat flow rate from the wall to the two-phase fluid 2 in the segment is

$$Q_{\text{seg}, 2P2} = UA_{\text{seg}, 2P2}(T_{\text{seg}, \text{wall}} - T_{\text{seg}, 2P2}),$$

where:

- $UA_{\text{seg}, 2P2}$  is the weighted-average heat transfer conductance for the two-phase fluid 2 in the segment.
- $T_{\text{seg}, 2P2}$  is the weighted-average fluid temperature for the two-phase fluid 2 in the segment.

### Two-Phase Fluid 1 Heat Transfer Correlation

If the segment is subcooled liquid, then the heat transfer conductance is

$$UA_{\text{seg}, L, 2P1} = a_{L, 2P1}(\text{Re}_{\text{seg}, L, 2P1})^{b_{2P1}}(\text{Pr}_{\text{seg}, L, 2P1})^{c_{2P1}}k_{\text{seg}, L, 2P1}\frac{G_{2P1}}{N},$$

where:

- $a_{L, 2P1}$ ,  $b_{2P1}$ , and  $c_{2P1}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $\text{Re}_{\text{seg}, L, 2P1}$  is the average liquid Reynolds number for the segment.
- $\text{Pr}_{\text{seg}, L, 2P1}$  is the average liquid Prandtl number for the segment.
- $k_{\text{seg}, L, 2P1}$  is the average liquid thermal conductivity for the segment.
- $G_{2P1}$  is the geometry scale factor for the two-phase fluid 1 side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average liquid Reynolds number is

$$\text{Re}_{\text{seg}, L, 2P1} = \frac{\dot{m}_{\text{seg}, 2P1}D_{\text{ref}, 2P1}}{\mu_{\text{seg}, L, 2P1}S_{\text{ref}, 2P1}},$$

where:

- $\dot{m}_{seg, 2P1}$  is the mass flow rate through the segment.
- $\mu_{seg,L,2P1}$  is the average liquid dynamic viscosity for the segment.
- $D_{ref,2P1}$  is an arbitrary reference diameter.
- $S_{ref,2P1}$  is an arbitrary reference flow area.

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**Note** The  $D_{ref,2P1}$  and  $S_{ref,2P1}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,L,2P1}$  nondimensional. The values of  $D_{ref,2P1}$  and  $S_{ref,2P1}$  are arbitrary because the  $G_{2P1}$  calculation overrides these values.

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Similarly, if the segment is superheated vapor, then the heat transfer conductance is

$$UA_{seg, V, 2P1} = a_{V, 2P1} (Re_{seg, V, 2P1})^{b_{2P1}} (Pr_{seg, V, 2P1})^{c_{2P1}} k_{seg, V, 2P1} \frac{G_{2P1}}{N},$$

where:

- $a_{V,2P1}$ ,  $b_{2P1}$ , and  $c_{2P1}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,V,2P1}$  is the average vapor Reynolds number for the segment.
- $Pr_{seg,V,2P1}$  is the average vapor Prandtl number for the segment.
- $k_{seg,V,2P1}$  is the average vapor thermal conductivity for the segment.

The average vapor Reynolds number is

$$Re_{seg, V, 2P1} = \frac{\dot{m}_{seg, 2P1} D_{ref, 2P1}}{\mu_{seg, V, 2P1} S_{ref, 2P1}},$$

where  $\mu_{seg,V,2P1}$  is the average vapor dynamic viscosity for the segment.

If the segment is liquid-vapor mixture, then the heat transfer conductance is

$$UA_{seg, M, 2P1} = a_{M, 2P1} (Re_{seg, SL, 2P1})^{b_{2P1}} CZ (Pr_{seg, SL, 2P1})^{c_{2P1}} k_{seg, SL, 2P1} \frac{G_{2P1}}{N},$$

where:

- $a_{M,2P1}$ ,  $b_{2P1}$ , and  $c_{2P1}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,SL,2P1}$  is the saturated liquid Reynolds number for the segment.
- $Pr_{seg,SL,2P1}$  is the saturated liquid Prandtl number for the segment.
- $k_{seg,SL,2P1}$  is the saturated liquid thermal conductivity for the segment.
- $CZ$  is the Cavallini and Zecchin term.

The saturated liquid Reynolds number is

$$Re_{seg, SL, 2P1} = \frac{\dot{m}_{seg, 2P1} D_{ref, 2P1}}{\mu_{seg, SL, 2P1} S_{ref, 2P1}},$$

where  $\mu_{seg,SL,2P1}$  is the saturated liquid dynamic viscosity for the segment.



The Cavallini and Zecchin term is

$$CZ = \frac{\left( \left( \sqrt{\frac{\nu_{seg,SV,2P1}}{\nu_{seg,SL,2P1}}} - 1 \right) (x_{seg,out,2P1} + 1) \right)^{1+b_{2P1}} - \left( \left( \sqrt{\frac{\nu_{seg,SV,2P1}}{\nu_{seg,SL,2P1}}} - 1 \right) (x_{seg,in,2P1} + 1) \right)^{1+b_{2P1}}}{(1+b_{2P1}) \left( \sqrt{\frac{\nu_{seg,SV,2P1}}{\nu_{seg,SL,2P1}}} - 1 \right) (x_{seg,out,2P1} - x_{seg,in,2P1})}$$

where:

- $\nu_{seg,SL,2P1}$  is the saturated liquid specific volume for the segment.
- $\nu_{seg,SV,2P1}$  is the saturated vapor specific volume for the segment.
- $x_{seg,in,2P1}$  is the vapor quality at the segment inlet.
- $x_{seg,out,2P1}$  is the vapor quality at the segment outlet.

The expression is based on the work of Cavallini and Zecchin [5], which derives a heat transfer coefficient correlation at a local vapor quality  $x$ . Equations for the liquid-vapor mixture are obtained by averaging Cavallini and Zecchin's correlation over the segment from  $x_{seg,in,2P1}$  to  $x_{seg,out,2P1}$ .

### Two-Phase Fluid 1 Weighted Average

The two-phase fluid flow through a segment may not be entirely represented as either subcooled liquid, superheated vapor, or liquid-vapor mixture. Instead, each segment may consist of a combination of these. The block approximates this condition by computing weighting factors ( $w_L$ ,  $w_V$ , and  $w_M$ ) based on the change in specific enthalpy across the segment and the saturated liquid and vapor specific enthalpies. The block assumes that the specific enthalpy across the segment varies piecewise linearly from inlet to outlet, with the breakpoints corresponding to the saturation boundaries for liquid and vapor. The zone with a larger heat transfer coefficient has a steeper slope than the zone with a lower heat transfer coefficient.

$$w_L = \frac{\Delta_L}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_V = \frac{\Delta_V}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_M = 1 - w_L - w_V$$

$$\Delta_L = \left| \min(h_{seg,out,2P1}, h_{seg,SL,2P1}) - \min(h_{seg,in,2P1}, h_{seg,SL,2P1}) \right| \cdot UA_{seg,M,2P1} \cdot UA_{seg,V,2P1}$$

$$\Delta_M = \left| \min(\max(h_{seg,out,2P1}, h_{seg,SL,2P1}), h_{seg,SV,2P1}) - \min(\max(h_{seg,in,2P1}, h_{seg,SL,2P1}), h_{seg,SV,2P1}) \right| \cdot UA_{seg,L,2P1} \cdot UA_{seg,M,2P1}$$

$$\Delta_V = \left| \max(h_{seg,out,2P1}, h_{seg,SV,2P1}) - \max(h_{seg,in,2P1}, h_{seg,SV,2P1}) \right| \cdot UA_{seg,L,2P1} \cdot UA_{seg,M,2P1}$$

where:

- $h_{seg,in,2P1}$  is the specific enthalpy at the segment inlet.
- $h_{seg,out,2P1}$  is the specific enthalpy at the segment outlet.
- $h_{seg,SL,2P1}$  is the saturated liquid specific enthalpy for the segment.
- $h_{seg,SV,2P1}$  is the saturated vapor specific enthalpy for the segment.

The weighted-average two-phase fluid 1 heat transfer conductance for the segment is therefore

$$UA_{seg,2P1} = w_L(UA_{seg,L,2P1}) + w_V(UA_{seg,V,2P1}) + w_M(UA_{seg,M,2P1}).$$

The weighted-average fluid 1 temperature for the segment is

$$T_{seg, 2P1} = \frac{w_L(UA_{seg, L, 2P1})T_{seg, L, 2P1} + w_V(UA_{seg, V, 2P1})T_{seg, V, 2P1} + w_M(UA_{seg, M, 2P1})T_{seg, M, 2P1}}{UA_{seg, 2P1}},$$

where:

- $T_{seg, L, 2P1}$  is the average liquid temperature for the segment.
- $T_{seg, V, 2P1}$  is the average vapor temperature for the segment.
- $T_{seg, M, 2P1}$  is the average mixture temperature for the segment, which is the saturated liquid temperature.

### Two-Phase Fluid 2 Heat Transfer Correlation

If the segment is subcooled liquid, then the heat transfer conductance is

$$UA_{seg, L, 2P2} = a_{L, 2P2}(Re_{seg, L, 2P2})^{b_{2P2}}(Pr_{seg, L, 2P2})^{c_{2P2}}k_{seg, L, 2P2}\frac{G_{2P2}}{N},$$

where:

- $a_{L, 2P2}$ ,  $b_{L, 2P2}$ , and  $c_{L, 2P2}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg, L, 2P2}$  is the average liquid Reynolds number for the segment.
- $Pr_{seg, L, 2P2}$  is the average liquid Prandtl number for the segment.
- $k_{seg, L, 2P2}$  is the average liquid thermal conductivity for the segment.
- $G_{2P2}$  is the geometry scale factor for the two-phase fluid 2 side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average liquid Reynolds number is

$$Re_{seg, L, 2P2} = \frac{\dot{m}_{seg, 2P2}D_{ref, 2P2}}{\mu_{seg, L, 2P2}S_{ref, 2P2}},$$

where:

- $\dot{m}_{seg, 2P2}$  is the mass flow rate through the segment.
- $\mu_{seg, L, 2P2}$  is the average liquid dynamic viscosity for the segment.
- $D_{ref, 2P2}$  is an arbitrary reference diameter.
- $S_{ref, 2P2}$  is an arbitrary reference flow area.

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**Note** The  $D_{ref, 2P2}$  and  $S_{ref, 2P2}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg, L, 2P2}$  nondimensional. The values of  $D_{ref, 2P2}$  and  $S_{ref, 2P2}$  are arbitrary because the  $G_{2P2}$  calculation overrides these values.

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Similarly, if the segment is superheated vapor, then the heat transfer conductance is

$$UA_{seg, V, 2P2} = a_{V, 2P2}(Re_{seg, V, 2P2})^{b_{2P2}}(Pr_{seg, V, 2P2})^{c_{2P2}}k_{seg, V, 2P2}\frac{G_{2P2}}{N},$$

where:

- $a_{V,2P2}$ ,  $b_{V,2P2}$ , and  $c_{V,2P2}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,V,2P2}$  is the average vapor Reynolds number for the segment.
- $Pr_{seg,V,2P2}$  is the average vapor Prandtl number for the segment.
- $k_{seg,V,2P2}$  is the average vapor thermal conductivity for the segment.

The average vapor Reynolds number is

$$Re_{seg,V,2P2} = \frac{\dot{m}_{seg,2P2} D_{ref,2P2}}{\mu_{seg,V,2P2} S_{ref,2P2}},$$

where  $\mu_{seg,V,2P2}$  is the average vapor dynamic viscosity for the segment.

If the segment is liquid-vapor mixture, then the heat transfer conductance is

$$UA_{seg,M,2P2} = a_{M,2P2} (Re_{seg,SL,2P2})^{b_{2P2}} CZ (Pr_{seg,SL,2P2})^{c_{2P2}} k_{seg,SL,2P2} \frac{G_{2P2}}{N},$$

where:

- $a_{M,2P2}$ ,  $b_{L,2P2}$ , and  $c_{L,2P2}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,SL,2P2}$  is the saturated liquid Reynolds number for the segment.
- $Pr_{seg,SL,2P2}$  is the saturated liquid Prandtl number for the segment.
- $k_{seg,SL,2P2}$  is the saturated liquid thermal conductivity for the segment.
- $CZ$  is the Cavallini and Zecchin term.

The saturated liquid Reynolds number is

$$Re_{seg,SL,2P2} = \frac{\dot{m}_{seg,2P2} D_{ref,2P2}}{\mu_{seg,SL,2P2} S_{ref,2P2}},$$

where  $\mu_{seg,SL,2P2}$  is the saturated liquid dynamic viscosity for the segment.

The Cavallini and Zecchin term is

$$CZ = \frac{\left( \left( \sqrt{\frac{\nu_{seg,SV,2P2}}{\nu_{seg,SL,2P2}}} - 1 \right) (x_{seg,out,2P2} + 1) \right)^{1+b_{2P2}} - \left( \left( \sqrt{\frac{\nu_{seg,SV,2P2}}{\nu_{seg,SL,2P2}}} - 1 \right) (x_{seg,in,2P2} + 1) \right)^{1+b_{2P2}}}{(1+b_{2P2}) \left( \sqrt{\frac{\nu_{seg,SV,2P2}}{\nu_{seg,SL,2P2}}} - 1 \right) (x_{seg,out,2P2} - x_{seg,in,2P2})},$$

where:

- $\nu_{seg,SL,2P2}$  is the saturated liquid specific volume for the segment.
- $\nu_{seg,SV,2P2}$  is the saturated vapor specific volume for the segment.
- $x_{seg,in,2P2}$  is the vapor quality at the segment inlet.
- $x_{seg,out,2P2}$  is the vapor quality at the segment outlet.

The expression is based on the work of Cavallini and Zecchin [5], which derives a heat transfer coefficient correlation at a local vapor quality  $x$ . Equations for the liquid-vapor mixture are obtained by averaging Cavallini and Zecchin's correlation over the segment from  $x_{\text{seg,in},2P2}$  to  $x_{\text{seg,out},2P2}$ .

### Two-Phase Fluid 2 Weighted Average

The two-phase fluid flow through a segment may not be entirely represented as either subcooled liquid, superheated vapor, or liquid-vapor mixture. Instead, each segment may consist of a combination of these. The block approximates this condition by computing weighting factors ( $w_L$ ,  $w_V$ , and  $w_M$ ) based on the change in specific enthalpy across the segment and the saturated liquid and vapor specific enthalpies. The block assumes that the specific enthalpy across the segment varies piecewise linearly from inlet to outlet, with the breakpoints corresponding to the saturation boundaries for liquid and vapor. The zone with a larger heat transfer coefficient has a steeper slope than the zone with a lower heat transfer coefficient.

$$w_L = \frac{\Delta_L}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_V = \frac{\Delta_V}{\Delta_L + \Delta_M + \Delta_V}$$

$$w_M = 1 - w_L - w_V$$

$$\Delta_L = |\min(h_{\text{seg,out},2P2}, h_{\text{seg,SL},2P2}) - \min(h_{\text{seg,in},2P2}, h_{\text{seg,SL},2P2})| \cdot UA_{\text{seg},M,2P2} \cdot UA_{\text{seg},V,2P2}$$

$$\Delta_M = |\min(\max(h_{\text{seg,out},2P2}, h_{\text{seg,SL},2P2}), h_{\text{seg,SV},2P2}) - \min(\max(h_{\text{seg,in},2P2}, h_{\text{seg,SL},2P2}), h_{\text{seg,SV},2P2})| \cdot UA_{\text{seg},L,2P2} \cdot UA_{\text{seg},M,2P2}$$

$$\Delta_V = |\max(h_{\text{seg,out},2P2}, h_{\text{seg,SV},2P2}) - \max(h_{\text{seg,in},2P2}, h_{\text{seg,SV},2P2})| \cdot UA_{\text{seg},L,2P2} \cdot UA_{\text{seg},M,2P2}$$

where:

- $h_{\text{seg,in},2P2}$  is the specific enthalpy at the segment inlet.
- $h_{\text{seg,out},2P2}$  is the specific enthalpy at the segment outlet.
- $h_{\text{seg,SL},2P2}$  is the saturated liquid specific enthalpy for the segment.
- $h_{\text{seg,SV},2P2}$  is the saturated vapor specific enthalpy for the segment.

The weighted-average two-phase fluid 2 heat transfer conductance for the segment is therefore

$$UA_{\text{seg},2P2} = w_L(UA_{\text{seg},L,2P2}) + w_V(UA_{\text{seg},V,2P2}) + w_M(UA_{\text{seg},M,2P2}).$$

The weighted-average fluid 2 temperature for the segment is

$$T_{\text{seg},2P2} = \frac{w_L(UA_{\text{seg},L,2P2})T_{\text{seg},L,2P2} + w_V(UA_{\text{seg},V,2P2})T_{\text{seg},V,2P2} + w_M(UA_{\text{seg},M,2P2})T_{\text{seg},M,2P2}}{UA_{\text{seg},2P2}},$$

where:

- $T_{\text{seg},L,2P2}$  is the average liquid temperature for the segment.
- $T_{\text{seg},V,2P2}$  is the average vapor temperature for the segment.
- $T_{\text{seg},M,2P2}$  is the average mixture temperature for the segment, which is the saturated liquid temperature.

### Pressure Loss

The pressure losses on the two-phase fluid 1 side are

$$p_{A,2P1} - p_{2P1} = \frac{K_{2P1} \dot{m}_{A,2P1} \sqrt{\dot{m}_{A,2P1}^2 + \dot{m}_{thres,2P1}^2}}{2 \rho_{avg,2P1}}$$

$$p_{B,2P1} - p_{2P1} = \frac{K_{2P1} \dot{m}_{B,2P1} \sqrt{\dot{m}_{B,2P1}^2 + \dot{m}_{thres,2P1}^2}}{2 \rho_{avg,2P1}}$$

where:

- $p_{A,2P1}$  and  $p_{B,2P1}$  are the pressures at ports **A1** and **B1**, respectively.
- $p_{2P1}$  is internal two-phase fluid 1 pressure at which the heat transfer is calculated.
- $\dot{m}_{A,2P1}$  and  $\dot{m}_{B,2P1}$  are the mass flow rates into ports **A1** and **B1**, respectively.
- $\rho_{avg,2P1}$  is the average two-phase fluid 1 density over all segments.
- $\dot{m}_{thres,2P1}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{2P1}$ , so that  $p_{A,2P1} - p_{B,2P1}$  matches the nominal pressure loss at the nominal mass flow rate.

The pressure losses on the two-phase fluid 2 side are

$$p_{A,2P2} - p_{2P2} = \frac{K_{2P2} \dot{m}_{A,2P2} \sqrt{\dot{m}_{A,2P2}^2 + \dot{m}_{thres,2P2}^2}}{2 \rho_{avg,2P2}}$$

$$p_{B,2P2} - p_{2P2} = \frac{K_{2P2} \dot{m}_{B,2P2} \sqrt{\dot{m}_{B,2P2}^2 + \dot{m}_{thres,2P2}^2}}{2 \rho_{avg,2P2}}$$

where:

- $p_{A,2P2}$  and  $p_{B,2P2}$  are the pressures at ports **A2** and **B2**, respectively.
- $p_{2P2}$  is internal two-phase fluid 2 pressure at which the heat transfer is calculated.
- $\dot{m}_{A,2P2}$  and  $\dot{m}_{B,2P2}$  are the mass flow rates into ports **A2** and **B2**, respectively.
- $\rho_{avg,2P2}$  is the average two-phase fluid 2 density over all segments.
- $\dot{m}_{thres,2P2}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{2P2}$ , so that  $p_{A,2P2} - p_{B,2P2}$  matches the nominal pressure loss at the nominal mass flow rate.

### Two-Phase Fluid 1 Mass and Energy Conservation

The mass conservation equation for the overall two-phase fluid 1 flow is

$$\left( \frac{dp_{2P1}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,2P1}}{\partial p} \right) + \sum_{segments} \left( \frac{du_{seg,2P1}}{dt} \frac{\partial \rho_{seg,2P1}}{\partial u} \right) \right) \frac{V_{2P1}}{N} = \dot{m}_{A,2P1} + \dot{m}_{B,2P1},$$

where:

- $\frac{\partial \rho_{seg,2P1}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,2P1}}{\partial u}$  is the partial derivative of density with respect to specific internal energy for the segment.

- $u_{seg,2P1}$  is the specific internal energy for the segment.
- $V_{2P1}$  is the total two-phase fluid 1 volume.

The summation is over all segments.

---

**Note** Although the two-phase fluid 1 flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{2P1}$ . That is why  $p_{2P1}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\frac{du_{seg,2P1}}{dt} \frac{M_{2P1}}{N} + u_{seg,2P1}(\dot{m}_{seg,in,2P1} - \dot{m}_{seg,out,2P1}) = \Phi_{seg,in,2P1} - \Phi_{seg,out,2P1} + Q_{seg,2P1},$$

where:

- $M_{2P1}$  is the total two-phase fluid 1 mass.
- $\dot{m}_{seg,in,2P1}$  and  $\dot{m}_{seg,out,2P1}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg,in,2P1}$  and  $\Phi_{seg,out,2P1}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A,2P1}$  and  $\dot{m}_{B,2P1}$ .

### Two-Phase Fluid 2 Mass and Energy Conservation

The mass conservation equation for the overall two-phase fluid 2 flow is

$$\left( \frac{dp_{2P2}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,2P2}}{\partial p} \right) + \sum_{segments} \left( \frac{du_{seg,2P2}}{dt} \frac{\partial \rho_{seg,2P2}}{\partial u} \right) \right) \frac{V_{2P2}}{N} = \dot{m}_{A,2P2} + \dot{m}_{B,2P2},$$

where:

- $\frac{\partial \rho_{seg,2P2}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,2P2}}{\partial u}$  is the partial derivative of density with respect to specific internal energy for the segment.
- $u_{seg,2P2}$  is the specific internal energy for the segment.
- $V_{2P2}$  is the total two-phase fluid 2 volume.

The summation is over all segments.

---

**Note** Although the two-phase fluid 2 flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{2P2}$ . That is why  $p_{2P2}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\frac{du_{seg, 2P2}}{dt} \frac{M_{2P2}}{N} + u_{seg, 2P2}(\dot{m}_{seg, in, 2P2} - \dot{m}_{seg, out, 2P2}) = \Phi_{seg, in, 2P2} - \Phi_{seg, out, 2P2} + Q_{seg, 2P2},$$

where:

- $M_{2P2}$  is the total two-phase fluid 2 mass.
- $\dot{m}_{seg, in, 2P2}$  and  $\dot{m}_{seg, out, 2P2}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg, in, 2P2}$  and  $\Phi_{seg, out, 2P2}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A, 2P2}$  and  $\dot{m}_{B, 2P2}$ .

## Ports

### Output

#### **Q1 — Rate of heat transfer to two-phase fluid 1, W**

physical signal

Rate of heat transfer to the first two-phase fluid network, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to On, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

#### **Q2 — Rate of heat transfer to two-phase fluid 2, W**

physical signal

Rate of heat transfer to the second two-phase fluid network, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to On, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

### Conserving

#### **A1 — Two-phase fluid port on side 1**

two-phase fluid

Inlet or outlet port associated with the first two-phase fluid network.

#### **B1 — Two-phase fluid port on side 1**

two-phase fluid

Inlet or outlet port associated with the first two-phase fluid network.

#### **A2 — Two-phase fluid port on side 2**

moist air

Inlet or outlet port associated with the second two-phase fluid network.

#### **B2 — Two-phase fluid port on side 2**

moist air

Inlet or outlet port associated with the second two-phase fluid network.

## Parameters

### Configuration

#### Flow arrangement at nominal operating condition — Flow path alignment

Counter flow - Two-Phase Fluid 1 flows from A to B, Two-Phase Fluid 2 flows from B to A (default) | Parallel flow - Both fluids flow from A to B | Cross flow - Both fluids flow from A to B

Flow path alignment between the heat exchanger sides at nominal operating condition. The available flow arrangements are:

- Counter flow - Two-Phase Fluid 1 flows from A to B, Two-Phase Fluid 2 flows from B to A — The flows run parallel to each other, in the opposite directions.
- Parallel flow - Both fluids flow from A to B — The flows run in the same direction.
- Cross flow - Both fluids flow from A to B — The flows run perpendicular to each other.

The choice between parallel flow and counter flow affects how the block determines the size of the heat exchanger. Counter flow is the most effective, therefore it will need the smallest size to meet the specified performance. Conversely, parallel flow is the least effective, therefore it will need the biggest size to meet the specified performance.

Flow direction at nominal condition (from A to B, or from B to A) affects only the model initialization, in case if you set the **Initial condition specification** parameter to Same as nominal operating condition. If you set up different initial operating conditions, the flow directions can be different.

Once the size is determined, the choice between parallel and counter does not play a role in how the block calculates the heat transfer during simulation. Instead, the heat transfer depends on the flow directions during simulation. If you set the parameter to parallel flow but set up the model to run in counter flow (or the other way around), then the rate of heat transfer during simulation will not match the specified performance, even if the rest of the boundary conditions are the same.

If you set the parameter to cross flow, then the flow paths are modeled as perpendicular inside the heat exchanger, so the flow directions during simulation do not matter.

#### Wall thermal mass — Enable or disable effect of thermal mass on heat transfer surface

Off (default) | On

Enable or disable the effect of thermal mass on the heat transfer surface. Setting this parameter to On introduces additional dynamics to the simulation, so that it takes longer to reach steady state, but does not affect the results at steady-state simulation.

#### Wall mass — Mass of heat transfer surface

1 kg (default) | positive scalar

Mass of the heat transfer surface.

#### Dependencies

To enable this parameter, set **Wall thermal mass** to On.

#### Wall specific heat — Specific heat of heat transfer surface

490 J/(K\*kg) (default) | positive scalar



Specific heat of the heat transfer surface.

#### Dependencies

To enable this parameter, set **Wall thermal mass** to 0n.

#### Cross-sectional area at port A1 — Flow area at port A1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid 1 port **A1**.

#### Cross-sectional area at port B1 — Flow area at port B1

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid 1 port **B1**.

#### Cross-sectional area at port A2 — Flow area at port A2

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid 2 port **A2**.

#### Cross-sectional area at port B2 — Area normal to flow at port B2

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the two-phase fluid 2 port **B2**.

#### Two-Phase Fluid 1

#### Nominal operating condition — Select whether nominal operating condition corresponds to condenser or evaporator

Heat transfer from two-phase fluid 1 to two-phase fluid 2 (default) | Heat transfer from two-phase fluid 2 to two-phase fluid 1

Select the nominal operating condition:

- Heat transfer from two-phase fluid 1 to two-phase fluid 2 — Side 1 is being cooled and side 2 is being heated.
- Heat transfer from two-phase fluid 2 to two-phase fluid 1 — Side 2 is being cooled and side1 is being heated.

This choice relates only to specifying the nominal operating condition parameters. It does not mean that heat transfer can only happen in the specified direction during simulation.

#### Nominal mass flow rate — Mass flow rate between two-phase fluid side 1 ports during nominal operating condition

0.001 kg/s (default) | positive scalar

Mass flow rate from port **A1** to port **B1** during the nominal operating condition.

#### Nominal pressure drop — Pressure drop between two-phase fluid side 1 ports during nominal operating condition

0.01 MPa (default) | positive scalar

Pressure drop from port **A1** to port **B1** during the nominal operating condition.

**Pressure specification — Select method of pressure specification**

Inlet pressure (default) | Saturation pressure at specified condensing temperature  
| Saturation pressure at specified evaporating temperature

Select the method of pressure specification:

- Inlet pressure — Specify the nominal inlet pressure.
- Saturation pressure at specified saturation temperature — Specify the nominal saturation temperature.

**Nominal inlet pressure — Pressure at the two-phase fluid side 1 inlet**

1 MPa (default) | positive scalar

Pressure at the inlet of the two-phase fluid side 1 of the heat exchanger during nominal operating condition.

**Dependencies**

To enable this parameter, set **Pressure specification** to Inlet pressure.

**Nominal saturation temperature — Use nominal saturation temperature to specify pressure**

313.15 K (default) | positive scalar

Saturation temperature at the outlet of the two-phase fluid side 1 of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal saturation temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Pressure specification** to Saturation pressure at specified saturation temperature.

**Inlet condition specification — Select quantity to describe the inlet condition of the two-phase fluid side 1**

Specific enthalpy (default) | Temperature | Vapor quality

Quantity used to describe the inlet condition of the fluid at the nominal operating condition: temperature, specific enthalpy, or vapor quality.

**Nominal inlet specific enthalpy — Specific enthalpy at the two-phase fluid side 1 inlet**

440 kJ/kg (default) | positive scalar

Specific enthalpy at the inlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Specific enthalpy.

**Nominal inlet temperature — Temperature at the two-phase fluid side 1 inlet**

313.15 K (default) | positive scalar

Temperature at the inlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Vapor quality at the two-phase fluid side 1 inlet**

1 (default) | positive scalar

Vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the inlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Vapor quality.

**Heat transfer capacity specification — Select how to specify heat transfer capacity of the two-phase fluid side 1**

Rate of heat transfer (default) | Outlet condition

Select whether to specify the performance of the heat exchanger at the nominal operating condition directly, by the rate of heat transfer, or indirectly, by the outlet condition.

**Nominal rate of heat transfer — Specify performance by rate of heat transfer**

0.1 kW (default) | positive scalar

Rate of heat transfer, depending on the nominal operating condition:

- If **Nominal operating condition** is Heat transfer from two-phase fluid 1 to two-phase fluid 2, rate of heat transfer from the two-phase fluid side 1 to side 2 during the nominal operating condition.
- If **Nominal operating condition** is Heat transfer from two-phase fluid 2 to two-phase fluid 1, rate of heat transfer from the two-phase fluid side 2 to side 1 during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Rate of heat transfer.

**Outlet condition specification — Select quantity for outlet condition specification**

Specific enthalpy (default) | Subcooling | Superheating | Vapor quality

Select the quantity for outlet condition specification:

- Specific enthalpy — Specify the nominal specific enthalpy.
- Subcooling — Specify the nominal subcooling. This option is available if you set **Nominal operating condition** to Heat transfer from two-phase fluid 1 to two-phase fluid 2.
- Superheating — Specify the nominal superheating. This option is available if you set **Nominal operating condition** to Heat transfer from two-phase fluid 2 to two-phase fluid 1.
- Vapor quality — Specify the nominal vapor quality.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Outlet condition.

**Nominal outlet specific enthalpy — Specific enthalpy at the two-phase fluid side 1 outlet**

250 kJ/kg (default) | positive scalar | two-element vector

Specific enthalpy at the outlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Specific enthalpy.

**Nominal subcooling — Degree of temperature below the liquid saturation temperature at the two-phase fluid side 1 outlet**

5 deltaK (default) | positive scalar

Degree of temperature below the liquid saturation temperature at the outlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Subcooling.

**Nominal superheating — Degree of temperature above the vapor saturation temperature at the two-phase fluid side 1 outlet**

5 deltaK (default) | positive scalar

Degree of temperature above the vapor saturation temperature at the outlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Superheating.

**Nominal outlet vapor quality — Vapor mass fraction at the two-phase fluid side 1 outlet**

0 (default) | scalar in the range [0,1]

Two-phase fluid vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the outlet of the two-phase fluid side 1 of the heat exchanger during the nominal operating condition.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Outlet condition specification** to Vapor quality.

**Two-phase fluid 1 volume — Total volume of two-phase fluid 1**

0.001 m<sup>3</sup> (default) | positive scalar

Total volume of two-phase fluid 1 inside the heat exchanger.

**Initial condition specification — Select how to specify initial state of two-phase fluid 1**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of two-phase fluid 1:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.

- **Specify initial condition** — Specify a different set of initial conditions using additional parameters.

#### **Initial fluid energy specification — Initial state of the two-phase fluid 1**

Specific enthalpy (default) | Temperature | Vapor quality | Vapor void fraction | Specific internal energy

Quantity used to describe the initial state of the side 1 fluid: temperature, vapor quality, vapor void fraction, specific enthalpy, or specific internal energy.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- **Temperature** — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- **Vapor quality** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Vapor void fraction** — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

#### **Dependencies**

To enable this parameter, set **Initial condition specification** to Specify initial condition.

#### **Initial two-phase fluid 1 pressure — Fluid 1 pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Two-phase fluid 1 pressure at the start of the simulation.

#### **Initial two-phase fluid 1 specific enthalpy — Enthalpy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid 1 specific enthalpy at the start of simulation. If the value is a scalar, then the initial specific enthalpy is assumed uniform. If the value is a two-element vector, then the initial specific enthalpy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

#### **Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

#### **Initial two-phase fluid 1 temperature — Temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Two-phase fluid 1 temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is

assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Temperature.

**Initial two-phase fluid 1 vapor quality — Vapor mass fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid 1 vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor quality is assumed uniform. If the value is a two-element vector, then the initial vapor quality is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

**Initial two-phase fluid 1 vapor void fraction — Vapor volume fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid 1 vapor void fraction, defined as the volume fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor void fraction is assumed uniform. If the value is a two-element vector, then the initial vapor void fraction is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

If using this option, the initial pressure cannot be higher than the critical pressure.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

**Initial two-phase fluid 1 specific internal energy — Internal energy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid 1 specific internal energy at the start of simulation. If the value is a scalar, then the initial specific internal energy is assumed uniform. If the value is a two-element vector, then the initial specific internal energy is assumed to vary linearly between ports **A1** and **B1**, with the first element corresponding to port **A1** and the second element corresponding to port **B1**.

**Dependencies**

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

**Two-Phase Fluid 2****Nominal mass flow rate — Mass flow rate between two-phase fluid side 2 ports during nominal operating condition**

0.001 kg/s (default) | positive scalar

Mass flow rate from port **A2** to port **B2** during the nominal operating condition.

**Nominal pressure drop — Pressure drop between two-phase fluid side 2 ports during nominal operating condition**

0.01 MPa (default) | positive scalar

Pressure drop from port **A2** to port **B2** during the nominal operating condition.

**Pressure specification — Select method of pressure specification**

Inlet pressure (default) | Saturation pressure at specified condensing temperature  
| Saturation pressure at specified evaporating temperature

Select the method of pressure specification:

- Inlet pressure — Specify the nominal inlet pressure.
- Saturation pressure at specified saturation temperature — Specify the nominal saturation temperature.

**Nominal inlet pressure — Pressure at the two-phase fluid side inlet**

1 MPa (default) | positive scalar

Pressure at the inlet of the two-phase fluid side 2 of the heat exchanger during nominal operating condition.

**Dependencies**

To enable this parameter, set **Pressure specification** to Inlet pressure.

**Nominal saturation temperature — Use nominal saturation temperature to specify pressure**

243.15 K (default) | positive scalar

Saturation temperature at the outlet of the two-phase fluid side 2 of the heat exchanger during nominal operating condition. The pressure in the heat exchanger is the corresponding saturation pressure. The nominal saturation temperature must be less than the critical temperature.

**Dependencies**

To enable this parameter, set **Pressure specification** to Saturation pressure at specified saturation temperature.

**Inlet condition specification — Select quantity to describe the inlet condition of the two-phase fluid side 2**

Specific enthalpy (default) | Temperature | Vapor quality

Quantity used to describe the inlet condition of the fluid at the nominal operating condition: temperature, specific enthalpy, or vapor quality.

**Nominal inlet specific enthalpy — Specific enthalpy at the two-phase fluid side 2 inlet**

250 kJ/kg (default) | positive scalar

Specific enthalpy at the inlet of the two-phase fluid side 2 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Specific enthalpy.

**Nominal inlet temperature — Temperature at the two-phase fluid side 2 inlet**

237.15 K (default) | positive scalar

Temperature at the inlet of the two-phase fluid side 2 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Temperature.

**Nominal inlet vapor quality — Vapor quality at the two-phase fluid side 2 inlet**

0.1 (default) | positive scalar

Vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the inlet of the two-phase fluid side 2 of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet condition specification** to Vapor quality.

**Two-phase fluid 2 volume — Total volume of two-phase fluid 2**0.001 m<sup>3</sup> (default) | positive scalar

Total volume of two-phase fluid 2 inside the heat exchanger.

**Initial condition specification — Select how to specify initial state of two-phase fluid 2**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of two-phase fluid 2:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial fluid energy specification — Initial state of the two-phase fluid 2**

Specific enthalpy (default) | Temperature | Vapor quality | Vapor void fraction | Specific internal energy

Quantity used to describe the initial state of the side 2 fluid.

The value for **Initial fluid energy specification** limits the available initial states for the two-phase fluid. When **Initial fluid energy specification** is:

- Temperature — Specify an initial state that is a subcooled liquid or superheated vapor. You cannot specify a liquid-vapor mixture because the temperature is constant across the liquid-vapor mixture region.
- Vapor quality — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.
- Vapor void fraction — Specify an initial state that is a liquid-vapor mixture. You cannot specify a subcooled liquid or a superheated vapor because the liquid mass fraction is 0 and 1, respectively, across the whole region. Additionally, the block limits the pressure to below the critical pressure.



- **Specific enthalpy** — Specify the specific enthalpy of the fluid. The block does not limit the initial state.
- **Specific internal energy** — Specify the specific internal energy of the fluid. The block does not limit the initial state.

#### Dependencies

To enable this parameter, set **Initial condition specification** to Specify initial condition.

#### **Initial two-phase fluid 2 pressure — Fluid 2 pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Two-phase fluid 2 pressure at the start of the simulation.

#### **Initial two-phase fluid 2 specific enthalpy — Enthalpy per unit mass at start of simulation**

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid 2 specific enthalpy at the start of simulation. If the value is a scalar, then the initial specific enthalpy is assumed uniform. If the value is a two-element vector, then the initial specific enthalpy is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

#### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Specific enthalpy.

#### **Initial two-phase fluid 2 temperature — Temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Two-phase fluid 2 temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

#### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Temperature.

#### **Initial two-phase fluid 2 vapor quality — Vapor mass fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid 2 vapor quality, defined as the mass fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor quality is assumed uniform. If the value is a two-element vector, then the initial vapor quality is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

If using this option, the initial pressure cannot be higher than the critical pressure.

#### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Vapor quality.

#### **Initial two-phase fluid 2 vapor void fraction — Vapor volume fraction at start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Two-phase fluid 2 vapor void fraction, defined as the volume fraction of vapor in a liquid-vapor mixture, at the start of simulation. If the value is a scalar, then the initial vapor void fraction is assumed uniform. If the value is a two-element vector, then the initial vapor void fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

If using this option, the initial pressure cannot be higher than the critical pressure.

#### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Vapor void fraction.

#### Initial two-phase fluid 2 specific internal energy – Internal energy per unit mass at start of simulation

1500 kJ/kg (default) | positive scalar | two-element vector

Two-phase fluid 2 specific internal energy at the start of simulation. If the value is a scalar, then the initial specific internal energy is assumed uniform. If the value is a two-element vector, then the initial specific internal energy is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

#### Dependencies

To enable this parameter, set **Initial fluid energy specification** to Specific internal energy.

#### Correlation Coefficients

##### **a** in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid 1 liquid – Correlation coefficient for subcooled liquid in two-phase fluid 1

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for subcooled liquid in two-phase fluid 1. The default value is based on the Colburn equation.

##### **a** in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid 1 mixture – Correlation coefficient for liquid-vapor mixture in two-phase fluid 1

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for liquid-vapor mixture in two-phase fluid 1. The default value is based on the Cavallini and Zecchin correlation.

##### **a** in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid 1 vapor – Correlation coefficient for superheated vapor in two-phase fluid 1

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for superheated vapor in two-phase fluid 1. The default value is based on the Colburn equation.

##### **b** in $Nu = a \cdot Re^b \cdot Pr^c$ for two-phase fluid 1 – Reynolds number exponent in correlation for two-phase fluid 1

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid 1. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 1 – Prandtl number exponent in correlation for two-phase fluid 1**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid 1. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 2 liquid – Correlation coefficient for subcooled liquid in two-phase fluid 2**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for subcooled liquid in two-phase fluid 2. The default value is based on the Colburn equation.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 2 mixture – Correlation coefficient for liquid-vapor mixture in two-phase fluid 2**

0.005 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for liquid-vapor mixture in two-phase fluid 2. The default value is based on the Cavallini and Zecchin correlation.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 2 vapor – Correlation coefficient for superheated vapor in two-phase fluid 2**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for superheated vapor in two-phase fluid 2. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 2 – Reynolds number exponent in correlation for two-phase fluid 2**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid 2. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for two-phase fluid 2 – Prandtl number exponent in correlation for two-phase fluid 2**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for two-phase fluid 2. The same value applies to subcooled liquid, liquid-vapor mixture, and superheated vapor.

## **Version History**

**Introduced in R2021b**

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

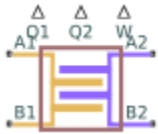
#### **See Also**

System-Level Condenser Evaporator (2P-MA) | System-Level Condenser Evaporator (2P-TL) | System-Level Heat Exchanger (TL-MA)

# System-Level Heat Exchanger (TL-MA)

Heat exchanger between thermal liquid and moist air networks, with model based on performance data

**Library:** Simscape / Fluids / Fluid Network Interfaces / Heat Exchangers



## Description

The System-Level Heat Exchanger (TL-MA) block models a heat exchanger between a thermal liquid network and a moist air network.

The block model is based on performance data from the heat exchanger datasheet, rather than on the detailed geometry of the exchanger, and therefore lets you easily adjust the size and performance of the heat exchanger during design iterations, or model heat exchangers with uncommon geometries. You can also use this block to model heat exchangers with a certain level of performance at an early design stage, when detailed geometry data is not yet available.

You parameterize the block by the nominal operating condition. The heat exchanger is sized to match the specified performance at the nominal operating condition at steady state.

The Moist Air 2 side models water vapor condensation based on convective water vapor mass transfer with the heat transfer surface. Condensed water is removed from the moist air flow.

This block is similar to the Heat Exchanger (TL-MA) block but uses a different parameterization model. The table provides a comparison of the two blocks, to help you choose the right block for your application.

Heat Exchanger (TL-MA)	System-Level Heat Exchanger (TL-MA)
Block parameters are based on the heat exchanger geometry	Block parameters are based on performance and operating conditions
Heat exchanger geometry may be limited by the available geometry parameter options	Model is independent of the specific heat exchanger geometry
You can adjust the block for different performance requirements by tuning geometry parameters, such as fin sizes and tube lengths	You can adjust the block for different performance requirements by directly specifying the desired heat and mass flow rates
Lets you select between parallel, counter, or cross flow configurations	Lets you select between parallel, counter, or cross flow arrangement at nominal operating conditions, to help with sizing
Predictively accurate results over a wide range of operating conditions, subject to the applicability of the E-NTU equations and the heat transfer coefficient correlations	Very accurate results around the specified operating condition; accuracy may decrease far away from the specified operating conditions

Heat Exchanger (TL-MA)	System-Level Heat Exchanger (TL-MA)
Heat transfer calculations account for the variation of temperature along the flow path by using the E-NTU model	Heat transfer calculations approximate the variation of temperature along the flow path by dividing it into three segments
Accounts for water vapor condensation and the latent heat on the moist air flow	Accounts for water vapor condensation and the latent heat on the moist air flow
Does not model the wall thermal mass; you can approximate the effect by connecting a pipe block with a thermal mass downstream	Includes an option to model the wall thermal mass

### Heat Transfer

The thermal liquid flow and the moist air flow are each divided into three segments of equal size. Heat transfer between the fluids is calculated in each segment. For simplicity, the equation for one segment is shown here.

If the wall thermal mass is off, then the heat balance in the heat exchanger is

$$Q_{seg, TL} + Q_{seg, MA} = 0,$$

where:

- $Q_{seg, TL}$  is the heat flow rate from the wall (that is, the heat transfer surface) to the thermal liquid in the segment.
- $Q_{seg, MA}$  is the heat flow rate from the wall to the moist air in the segment.

If the wall thermal mass is on, then the heat balance in the heat exchanger is

$$Q_{seg, TL} + Q_{seg, MA} = - \frac{M_{wall} c_{pwall}}{N} \frac{dT_{seg, wall}}{dt},$$

where:

- $M_{wall}$  is the mass of the wall.
- $c_{pwall}$  is the specific heat of the wall.
- $N = 3$  is the number of segments.
- $T_{seg, wall}$  is the average wall temperature in the segment.
- $t$  is time.

The heat flow rate from the wall to the thermal liquid in the segment is

$$Q_{seg, TL} = UA_{seg, TL}(T_{seg, wall} - T_{seg, TL}),$$

where:

- $UA_{seg, TL}$  is the heat transfer conductance for the thermal liquid in the segment.
- $T_{seg, TL}$  is the average liquid temperature in the segment.

The heat flow rate from the wall to the moist air in the segment is

$$Q_{seg, MA} = \frac{UA_{seg, MA}}{\bar{c}_{pseg, MA}} (\bar{h}_{seg, wall} - \bar{h}_{seg, MA}) + \dot{m}_{w, seg, cond} h_{l, wall}$$

where:

- $UA_{seg,MA}$  is the heat transfer conductance for the moist air in the segment.
- $\bar{c}_{pseg,MA}$  is the moist air mixture specific heat per unit mass of dry air and trace gas in the segment.
- $\bar{h}_{seg,wall}$  is the moist air mixture enthalpy per unit mass of dry air and trace gas at the average wall segment temperature.
- $\bar{h}_{seg,MA}$  is the moist air mixture enthalpy per unit mass of dry air and trace gas in the segment.
- $\dot{m}_{w,seg,cond}$  is the rate of water vapor condensation on the wall surface.
- $h_{l,wall}$  is the specific enthalpy of liquid water at the average wall segment temperature.

Using mixture enthalpy in this equation accounts for both differences in temperature and differences in moisture due to condensation [3].

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**Note** For the moist air quantities, the bar above the symbols indicates that they are quantities for mixture divided by the mass of dry air and trace gas only, as opposed to dividing by the mass of the whole mixture. The whole mixture includes dry air, water vapor, and trace gas.

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### Thermal Liquid Heat Transfer Correlation

The heat transfer conductance is

$$UA_{seg,TL} = a_{TL}(Re_{seg,TL})^{b_{TL}}(Pr_{seg,TL})^{c_{TL}}k_{seg,TL}\frac{G_{TL}}{N},$$

where:

- $a_{TL}$ ,  $b_{TL}$ , and  $c_{TL}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,TL}$  is the average Reynolds number for the segment.
- $Pr_{seg,TL}$  is the average Prandtl number for the segment.
- $k_{seg,TL}$  is the average thermal conductivity for the segment.
- $G_{TL}$  is the geometry scale factor for the thermal liquid side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average Reynolds number is

$$Re_{seg,TL} = \frac{\dot{m}_{seg,TL}D_{ref,TL}}{\mu_{seg,TL}S_{ref,TL}},$$

where:

- $\dot{m}_{seg,TL}$  is the mass flow rate through the segment.
- $\mu_{seg,TL}$  is the average dynamic viscosity for the segment.
- $D_{ref,TL}$  is an arbitrary reference diameter.
- $S_{ref,TL}$  is an arbitrary reference flow area.

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**Note** The  $D_{ref,TL}$  and  $S_{ref,TL}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,TL}$  nondimensional. The values of  $D_{ref,TL}$  and  $S_{ref,TL}$  are arbitrary because the  $G_{TL}$  calculation overrides these values.

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### Moist Air Heat Transfer Correlation

The heat transfer conductance is

$$UA_{seg,MA} = a_{MA}(Re_{seg,MA})^{b_{MA}}(Pr_{seg,MA})^{c_{MA}}k_{seg,MA}\frac{G_{MA}}{N},$$

where:

- $a_{MA}$ ,  $b_{MA}$ , and  $c_{MA}$  are the coefficients of the Nusselt number correlation. These coefficients appear as block parameters in the **Correlation Coefficients** section.
- $Re_{seg,MA}$  is the average Reynolds number for the segment.
- $Pr_{seg,MA}$  is the average Prandtl number for the segment.
- $k_{seg,MA}$  is the average thermal conductivity for the segment.
- $G_{MA}$  is the geometry scale factor for the moist air side of the heat exchanger. The block calculates the geometry scale factor so that the total heat transfer over all segments matches the specified performance at the nominal operating conditions.

The average Reynolds number is

$$Re_{seg,MA} = \frac{\dot{m}_{seg,MA}D_{ref,MA}}{\mu_{seg,MA}S_{ref,MA}},$$

where:

- $\dot{m}_{seg,MA}$  is the mass flow rate through the segment.
- $\mu_{seg,MA}$  is the average dynamic viscosity for the segment.
- $D_{ref,MA}$  is an arbitrary reference diameter.
- $S_{ref,MA}$  is an arbitrary reference flow area.

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**Note** The  $D_{ref,MA}$  and  $S_{ref,MA}$  terms are included in this equation for unit calculation purposes only, to make  $Re_{seg,MA}$  nondimensional. The values of  $D_{ref,MA}$  and  $S_{ref,MA}$  are arbitrary because the  $G_{MA}$  calculation overrides these values.

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### Moist Air Condensation

The equation describing the heat flow rate from the wall to the moist air in the segment (the last equation in the “Heat Transfer” on page 1-1784 section) uses the average moist air mixture enthalpy,  $\bar{h}_{seg,MA}$ , and the wall segment moist air mixture enthalpy,  $\bar{h}_{seg,wall}$ .

The average moist air mixture enthalpy is based on the temperature and humidity of the moist air flow through the segment:

$$\bar{h}_{seg,MA} = h_{seg,ag,MA} + W_{seg,MA}h_{seg,w,MA}$$



where:

- $h_{seg,ag,MA}$  is the average specific enthalpy of dry air and trace gas for the segment.
- $h_{seg,w,MA}$  is the average specific enthalpy of water vapor for the segment.
- $W_{seg,MA}$  is the humidity ratio of the segment.

The wall segment moist air mixture enthalpy is based on the temperature and humidity at the wall segment:

$$\bar{h}_{seg,wall} = h_{seg,ag,wall} + W_{seg,wall}h_{seg,w,wall},$$

where:

- $h_{seg,ag,wall}$  is the specific enthalpy of dry air and trace gas at the wall segment temperature.
- $h_{seg,w,wall}$  is the specific enthalpy of water vapor at the wall segment temperature.
- $W_{seg,wall}$  is the humidity ratio at the wall segment:

$$W_{seg,wall} = \min(W_{seg,MA}, W_{seg,s,wall}),$$

where  $W_{seg,s,wall}$  is the saturated humidity ratio at the wall segment temperature. In other words, the humidity ratio at the wall is the same as the humidity ratio of the moist air flow but not more than the maximum that can be supported at the wall segment temperature.

When  $W_{seg,s,wall} < W_{seg,MA}$ , water vapor condensation occurs on the wall surface. The rate of water vapor condensation is

$$\dot{m}_{w,seg,cond} = \frac{UA_{seg,MA}}{\bar{c}p_{seg,MA}}(W_{seg,MA} - W_{seg,wall}).$$

The condensed water is assumed to be drained from the wall surface and is thus removed from the moist air flow downstream.

### Pressure Loss

The pressure losses on the thermal liquid side are

$$p_{A,TL} - p_{TL} = \frac{K_{TL}}{2} \frac{\dot{m}_{A,TL} \sqrt{\dot{m}_{A,TL}^2 + \dot{m}_{thres,TL}^2}}{2\rho_{avg,2P}}$$

$$p_{B,TL} - p_{TL} = \frac{K_{TL}}{2} \frac{\dot{m}_{B,TL} \sqrt{\dot{m}_{B,TL}^2 + \dot{m}_{thres,TL}^2}}{2\rho_{avg,TL}}$$

where:

- $p_{A,TL}$  and  $p_{B,TL}$  are the pressures at ports **A2** and **B2**, respectively.
- $p_{TL}$  is internal thermal liquid pressure at which the heat transfer is calculated.
- $\dot{m}_{A,TL}$  and  $\dot{m}_{B,TL}$  are the mass flow rates into ports **A2** and **B2**, respectively.
- $\rho_{avg,TL}$  is the average thermal liquid density over all segments.
- $\dot{m}_{thres,TL}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{TL}$ , so that  $p_{A,TL} - p_{B,TL}$  matches the nominal pressure loss at the nominal mass flow rate.

The pressure losses on the moist air side are

$$p_{A,MA} - p_{MA} = \frac{K_{MA} \dot{m}_{A,MA} \sqrt{\dot{m}_{A,MA}^2 + \dot{m}_{thres,MA}^2}}{2 \rho_{avg,2P}}$$

$$p_{B,MA} - p_{MA} = \frac{K_{MA} \dot{m}_{B,MA} \sqrt{\dot{m}_{B,MA}^2 + \dot{m}_{thres,MA}^2}}{2 \rho_{avg,MA}}$$

where:

- $p_{A,MA}$  and  $p_{B,MA}$  are the pressures at ports **A2** and **B2**, respectively.
- $p_{MA}$  is internal moist air pressure at which the heat transfer is calculated.
- $\dot{m}_{A,MA}$  and  $\dot{m}_{B,MA}$  are the mass flow rates into ports **A2** and **B2**, respectively.
- $\rho_{avg,MA}$  is the average moist air density over all segments.
- $\dot{m}_{thres,MA}$  is the laminar threshold for pressure loss, approximated as 1e-4 of the nominal mass flow rate. The block calculates the pressure loss coefficient,  $K_{MA}$ , so that  $p_{A,MA} - p_{B,MA}$  matches the nominal pressure loss at the nominal mass flow rate.

### Thermal Liquid Mass and Energy Conservation

The mass conservation for the overall thermal liquid flow is

$$\left( \frac{dp_{TL}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg,TL}}{\partial p} \right) + \sum_{segments} \left( \frac{dT_{seg,TL}}{dt} \frac{\partial \rho_{seg,TL}}{\partial T} \right) \right) \frac{V_{TL}}{N} = \dot{m}_{A,TL} + \dot{m}_{B,TL}$$

where:

- $\frac{\partial \rho_{seg,TL}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg,TL}}{\partial T}$  is the partial derivative of density with respect to temperature for the segment.
- $T_{seg,TL}$  is the temperature for the segment.
- $V_{TL}$  is the total thermal liquid volume.

The summation is over all segments.

---

**Note** Although the thermal liquid flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{TL}$ . That is why  $p_{TL}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\left( \frac{dp_{TL}}{dt} \frac{\partial u_{seg,TL}}{\partial p} + \frac{dT_{seg,TL}}{dt} \frac{\partial u_{seg,TL}}{\partial T} \right) \frac{M_{TL}}{N} + u_{seg,TL} (\dot{m}_{seg,in,TL} - \dot{m}_{seg,out,TL}) = \Phi_{seg,in,TL} - \Phi_{seg,out,TL} + Q_{seg,TL}$$

where:

- $\frac{\partial u_{seg, TL}}{\partial p}$  is the partial derivative of specific internal energy with respect to pressure for the segment.
- $\frac{\partial u_{seg, TL}}{\partial T}$  is the partial derivative of specific internal energy with respect to temperature for the segment.
- $M_{TL}$  is the total thermal liquid mass.
- $\dot{m}_{seg, in, TL}$  and  $\dot{m}_{seg, out, TL}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg, in, TL}$  and  $\Phi_{seg, out, TL}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A, TL}$  and  $\dot{m}_{B, TL}$ .

### Moist Air Mass and Energy Conservation

The mass conservation for the overall moist air mixture flow is

$$\left( \frac{dp_{MA}}{dt} \sum_{segments} \left( \frac{\partial \rho_{seg, MA}}{\partial p} \right) + \sum_{segments} \left( \frac{dT_{seg, MA}}{dt} \frac{\partial \rho_{seg, MA}}{\partial T} + \frac{dx_{w, seg, MA}}{dt} \frac{\partial \rho_{seg, MA}}{\partial x_w} + \frac{dx_{g, seg, MA}}{dt} \frac{\partial \rho_{seg, MA}}{\partial x_g} \right) \right) \frac{V_{MA}}{N} = \dot{m}_{A, MA} + \dot{m}_{B, MA} - \sum_{segments} (\dot{m}_{w, seg, cond}),$$

where:

- $\frac{\partial \rho_{seg, MA}}{\partial p}$  is the partial derivative of density with respect to pressure for the segment.
- $\frac{\partial \rho_{seg, MA}}{\partial T}$  is the partial derivative of density with respect to temperature for the segment.
- $\frac{\partial \rho_{seg, MA}}{\partial x_w}$  is the partial derivative of density with respect to specific humidity for the segment.
- $\frac{\partial \rho_{seg, MA}}{\partial x_g}$  is the partial derivative of density with respect to trace gas mass fraction for the segment.
- $x_{w, seg, MA}$  is the specific humidity, that is, the water vapor mass fraction, for the segment.
- $x_{g, seg, MA}$  is the trace gas mass fraction for the segment.
- $V_{MA}$  is the total moist air volume.

The summation is over all segments.

---

**Note** Although the moist air flow is divided into  $N=3$  segments for heat transfer calculations, all segments are assumed to be at the same internal pressure,  $p_{MA}$ . That is why  $p_{MA}$  is outside of the summation.

---

The energy conservation equation for each segment is

$$\left( \frac{dT_{seg, MA}}{dt} \frac{\partial u_{seg, MA}}{\partial T} + \frac{dx_{w, seg, MA}}{dt} \frac{\partial u_{seg, MA}}{\partial x_w} + \frac{dx_{g, seg, MA}}{dt} \frac{\partial u_{seg, MA}}{\partial x_g} \right) \frac{M_{MA}}{N} + u_{seg, MA} (\dot{m}_{seg, in, MA} - \dot{m}_{seg, out, MA}) - \Phi_{seg, in, MA} - \Phi_{seg, out, MA} + Q_{seg, MA} - \dot{m}_{w, seg, cond} h_{l, wall},$$

where:

- $\frac{\partial u_{seg,MA}}{\partial T}$  is the partial derivative of specific internal energy with respect to temperature for the segment.
- $\frac{\partial u_{seg,MA}}{\partial x_w}$  is the partial derivative of specific internal energy with respect to specific humidity for the segment.
- $\frac{\partial u_{seg,MA}}{\partial x_g}$  is the partial derivative of specific internal energy with respect to trace gas mass fraction for the segment.
- $u_{seg,2P}$  is the specific internal energy for the segment.
- $M_{MA}$  is the total moist air mass.
- $\dot{m}_{seg,in,MA}$  and  $\dot{m}_{seg,out,MA}$  are the mass flow rates into and out of the segment.
- $\Phi_{seg,in,MA}$  and  $\Phi_{seg,out,MA}$  are the energy flow rates into and out of the segment.

The mass flow rates between segments are assumed to be linearly distributed between the values of  $\dot{m}_{A,MA}$  and  $\dot{m}_{B,MA}$ .

The water vapor mass conservation equation for each segment is

$$\frac{dx_{w,seg,MA}}{dt} \frac{M_{MA}}{N} + x_{w,seg,MA}(\dot{m}_{seg,in,MA} - \dot{m}_{seg,out,MA}) = \dot{m}_{w,seg,in,MA} - \dot{m}_{w,seg,out,MA} - \dot{m}_{w,seg,cond}$$

where  $\dot{m}_{w,seg,in,MA}$  and  $\dot{m}_{w,seg,out,MA}$  are the water vapor mass flow rates into and out of the segment.

The trace gas mass conservation equation for each segment is

$$\frac{dx_{g,seg,MA}}{dt} \frac{M_{MA}}{N} + x_{g,seg,MA}(\dot{m}_{seg,in,MA} - \dot{m}_{seg,out,MA}) = \dot{m}_{g,seg,in,MA} - \dot{m}_{g,seg,out,MA}$$

where  $\dot{m}_{g,seg,in,MA}$  and  $\dot{m}_{g,seg,out,MA}$  are the trace gas mass flow rates into and out of the segment.

## Ports

### Output

#### Q1 — Rate of heat transfer to thermal liquid, W

physical signal

Rate of heat transfer to thermal liquid, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to **On**, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

#### Q2 — Rate of heat transfer to moist air, W

physical signal

Rate of heat transfer to moist air, returned as a physical signal. Physical signals **Q1** and **Q2** are usually equal in value with opposite sign. However, if the **Wall thermal mass** parameter is set to **On**, then these two signals may have different values because the wall may absorb and release some of the heat being transferred.

### **W — Moist air condensation rate, kg/s**

physical signal

Water condensation rate in the moist air flow, returned as a physical signal. The condensate does not accumulate on the heat transfer surface.

## **Conserving**

### **A1 — Thermal liquid port**

thermal liquid

Inlet or outlet port associated with the thermal liquid.

### **B1 — Thermal liquid port**

thermal liquid

Inlet or outlet port associated with the thermal liquid.

### **A2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

### **B2 — Moist air port**

moist air

Inlet or outlet port associated with the moist air.

## **Parameters**

### **Configuration**

#### **Flow arrangement at nominal operating condition — Flow path alignment**

Counter flow - Thermal Liquid 1 flows from A to B, Moist Air 2 flows from B to A (default) | Parallel flow - Both fluids flow from A to B | Cross flow - Both fluids flow from A to B

Flow path alignment between the heat exchanger sides at nominal operating condition. The available flow arrangements are:

- Counter flow - Thermal Liquid 1 flows from A to B, Moist Air 2 flows from B to A — The flows run parallel to each other, in the opposite directions.
- Parallel flow - Both fluids flow from A to B — The flows run in the same direction.
- Cross flow - Both fluids flow from A to B — The flows run perpendicular to each other.

The choice between parallel flow and counter flow affects how the block determines the size of the heat exchanger. Counter flow is the most effective, therefore it will need the smallest size to meet the

specified performance. Conversely, parallel flow is the least effective, therefore it will need the biggest size to meet the specified performance.

Flow direction at nominal condition (from A to B, or from B to A) affects only the model initialization, in case if you set the **Initial condition specification** parameter to `Same as nominal operating condition`. If you set up different initial operating conditions, the flow directions can be different.

Once the size is determined, the choice between parallel and counter does not play a role in how the block calculates the heat transfer during simulation. Instead, the heat transfer depends on the flow directions during simulation. If you set the parameter to parallel flow but set up the model to run in counter flow (or the other way around), then the rate of heat transfer during simulation will not match the specified performance, even if the rest of the boundary conditions are the same.

If you set the parameter to cross flow, then the flow paths are modeled as perpendicular inside the heat exchanger, so the flow directions during simulation do not matter.

**Wall thermal mass — Enable or disable effect of thermal mass on heat transfer surface**  
Off (default) | On

Enable or disable the effect of thermal mass on the heat transfer surface. Setting this parameter to `On` introduces additional dynamics to the simulation, so that it takes longer to reach steady state, but does not affect the results at steady-state simulation.

**Wall mass — Mass of heat transfer surface**  
1 kg (default) | positive scalar

Mass of the heat transfer surface.

#### **Dependencies**

To enable this parameter, set **Wall thermal mass** to `On`.

**Wall specific heat — Specific heat of heat transfer surface**  
490 J/(K\*kg) (default) | positive scalar

Specific heat of the heat transfer surface.

#### **Dependencies**

To enable this parameter, set **Wall thermal mass** to `On`.

**Cross-sectional area at port A1 — Flow area at port A1**  
0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **A1**.

**Cross-sectional area at port B1 — Flow area at port B1**  
0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the thermal liquid port **B1**.

**Cross-sectional area at port A2 — Flow area at port A2**  
0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the moist air port **A2**.

**Cross-sectional area at port B2 — Area normal to flow at port B2**0.01 m<sup>2</sup> (default) | positive scalarFlow area at the moist air port **B2**.**Thermal Liquid 1****Nominal operating condition — Select nominal operating condition**

Heat transfer from thermal liquid to moist air (default) | Heat transfer from moist air to thermal liquid

Select the nominal operating condition:

- Heat transfer from thermal liquid to moist air — The thermal liquid is being cooled and the moist air is being heated.
- Heat transfer from moist air to thermal liquid — The moist air is being cooled and the thermal liquid is being heated.

This choice relates only to specifying the nominal operating condition parameters. It does not mean that heat transfer can only happen in the specified direction during simulation.

**Nominal mass flow rate — Mass flow rate between thermal liquid ports during nominal operating condition**

0.1 kg/s (default) | positive scalar

Mass flow rate from port **A1** to port **B1** during the nominal operating condition.**Nominal pressure drop — Pressure drop between thermal liquid ports during nominal operating condition**

0.01 MPa (default) | positive scalar

Pressure drop from port **A1** to port **B1** during the nominal operating condition.**Nominal inlet pressure — Pressure at the thermal liquid inlet**

0.101325 MPa (default) | positive scalar

Pressure at the inlet of the thermal liquid of the heat exchanger during nominal operating condition.

**Nominal inlet temperature — Temperature at the thermal liquid inlet**

333.15 K (default) | positive scalar

Temperature at the inlet of the thermal liquid of the heat exchanger during the nominal operating condition.

**Heat transfer capacity specification — Select how to specify heat transfer capacity of the thermal liquid**

Rate of heat transfer (default) | Outlet condition

Select whether to specify the performance of the heat exchanger at the nominal operating condition directly, by the rate of heat transfer, or indirectly, by the outlet condition.

**Nominal rate of heat transfer — Specify performance by rate of heat transfer**

1 kW (default) | positive scalar

Rate of heat transfer, depending on the nominal operating condition:

- If **Nominal operating condition** is Heat transfer from thermal liquid to moist air, rate of heat transfer from the thermal liquid to the moist air during the nominal operating condition.
- If **Nominal operating condition** is Heat transfer from moist air to thermal liquid, rate of heat transfer from the moist air to the thermal liquid during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Rate of heat transfer.

**Nominal outlet temperature — Specify performance by outlet temperature**

323.15 K (default) | positive scalar

Temperature at the outlet of the thermal liquid of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Heat transfer capacity specification** to Outlet condition.

**Thermal liquid volume — Total volume of thermal liquid**

0.001 m<sup>3</sup> (default) | positive scalar

Total volume of thermal liquid inside the heat exchanger.

**Initial condition specification — Select how to specify initial state of thermal liquid**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of thermal liquid:

- Same as nominal operating condition — Start the simulation at the nominal operating condition.
- Specify initial condition — Specify a different set of initial conditions using additional parameters.

**Initial thermal liquid pressure — Thermal liquid pressure at the start of simulation**

0.101325 MPa (default) | positive scalar

Thermal liquid pressure at the start of simulation.

**Dependencies**

To enable this parameter, set **Initial condition specification** to Specify initial condition.

**Initial thermal liquid temperature — Thermal liquid temperature at the start of simulation**

293.15 K (default) | positive scalar

Thermal liquid temperature at the start of simulation.

**Dependencies**

To enable this parameter, set **Initial condition specification** to Specify initial condition.



## Moist Air 2

### Nominal mass flow rate — Mass flow rate between moist air ports during nominal operating condition

0.1 kg/s (default) | positive scalar

Mass flow rate from port **A2** to port **B2** during the nominal operating condition.

### Nominal pressure drop — Pressure drop between moist air ports during nominal operating condition

0.001 MPa (default) | positive scalar

Pressure drop from port **A2** to port **B2** during the nominal operating condition.

### Nominal inlet pressure — Pressure at the moist air side inlet

0.101325 MPa (default) | positive scalar

Pressure at the inlet of the moist air side of the heat exchanger during nominal operating condition.

### Nominal inlet temperature — Temperature at the moist air side inlet

293.15 K (default) | positive scalar

Temperature at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

### Inlet moisture specification — Quantity used to describe the moisture level at the moist air side inlet

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Select quantity used to describe the moisture level at the inlet during the nominal operating condition: relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

### Nominal inlet relative humidity — Relative humidity at the inlet

0.5 (default) | scalar in the range [0,1]

Relative humidity at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

#### Dependencies

To enable this parameter, set **Inlet moisture specification** to Relative humidity.

### Nominal inlet specific humidity — Specific humidity at the inlet

0.01 (default) | scalar in the range [0,1]

Specific humidity, defined as the mass fraction of water vapor in a moist air mixture, at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

#### Dependencies

To enable this parameter, set **Inlet moisture specification** to Specific humidity.

### Nominal inlet water vapor mole fraction — Mole fraction of water vapor at the inlet

0.01 (default) | scalar in the range [0,1]

Mole fraction of water vapor in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Mole fraction.

**Nominal inlet humidity ratio – Humidity ratio at the inlet**

0.01 (default) | positive scalar in the range [0,1]

Humidity ratio, defined as the mass ratio of water vapor to dry air and trace gas, at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

**Dependencies**

To enable this parameter, set **Inlet moisture specification** to Humidity ratio.

**Inlet trace gas specification – Quantity used to describe trace gas level at the inlet**

Mass fraction (default) | Mole fraction

Select quantity used to describe the trace gas level at the inlet during the nominal operating condition: mass fraction or mole fraction.

**Nominal inlet trace gas mass fraction – Mass fraction of trace gas at the inlet**

0.001 (default) | scalar in the range [0,1]

Mass fraction of trace gas in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Inlet trace gas specification** to Mass fraction.

**Nominal inlet trace gas mole fraction – Mole fraction of trace gas at the inlet**

0.001 (default) | scalar in the range [0,1]

Mole fraction of trace gas in a moist air mixture at the inlet of the moist air side of the heat exchanger during the nominal operating condition.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Inlet trace gas specification** to Mole fraction.

**Moist air volume – Total volume of moist air in the heat exchanger**

0.1 m<sup>3</sup> (default) | positive scalar

Total volume of moist air in the heat exchanger.

**Initial condition specification – Select how to specify initial state of moist air**

Same as nominal operating condition (default) | Specify initial condition

Select how to specify initial state of moist air:

- Same as nominal operating condition – Start the simulation at the nominal operating condition.

- **Specify initial condition** — Specify a different set of initial conditions using additional parameters.

**Initial moist air pressure — Moist air pressure at start of simulation**

0.101325 MPa (default) | positive scalar

Moist air pressure at the start of the simulation.

**Initial moist air temperature — Moist air temperature at start of simulation**

293.15 K (default) | positive scalar | two-element vector

Moist air temperature at the start of simulation. If the value is a scalar, then the initial temperature is assumed uniform. If the value is a two-element vector, then the initial temperature is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Initial moisture specification — Quantity used to describe the initial moisture level**

Relative humidity (default) | Specific humidity | Mole fraction | Humidity ratio

Select quantity used to describe the initial moisture level: relative humidity, specific humidity, water vapor mole fraction, or humidity ratio.

**Initial moist air relative humidity — Relative humidity at the start of simulation**

0.5 (default) | scalar in the range [0,1] | two-element vector

Moist air relative humidity at the start of simulation. If the value is a scalar, then the initial relative humidity is assumed uniform. If the value is a two-element vector, then the initial relative humidity is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Relative humidity.

**Initial moist air specific humidity — Specific humidity at the start of simulation**

0.01 (default) | scalar in the range [0,1] | two-element vector

Moist air specific humidity, defined as the mass fraction of water vapor in a moist air mixture, at the start of simulation. If the value is a scalar, then the initial specific humidity is assumed uniform. If the value is a two-element vector, then the initial specific humidity is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Specific humidity.

**Initial moist air water vapor mole fraction — Mole fraction of water vapor at the start of simulation**

0.01 (default) | scalar in the range [0,1] | two-element vector

Mole fraction of water vapor in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mole fraction is assumed uniform. If the value is a two-element vector, then the initial mole fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Mole fraction.

**Initial moist air humidity ratio – Humidity ratio at the start of simulation**

0.01 (default) | positive scalar in the range [0,1] | two-element vector

Moist air humidity ratio, defined as the mass ratio of water vapor to dry air and trace gas, at the start of simulation. If the value is a scalar, then the initial humidity ratio is assumed uniform. If the value is a two-element vector, then the initial humidity ratio is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

**Dependencies**

To enable this parameter, set **Initial moisture specification** to Humidity ratio.

**Initial trace gas specification – Quantity used to describe initial trace gas level**

Mass fraction (default) | Mole fraction

Select quantity used to describe the trace gas level at the start of simulation: mass fraction or mole fraction.

**Initial moist air trace gas mass fraction – Mass fraction of trace gas at the start of simulation**

0.001 (default) | scalar in the range [0,1] | two-element vector

Mass fraction of trace gas in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mass fraction is assumed uniform. If the value is a two-element vector, then the initial mass fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Initial trace gas specification** to Mass fraction.

**Initial moist air trace gas mole fraction – Mole fraction of trace gas at the start of simulation**

0.001 (default) | scalar in the range [0,1] | two-element vector

Mole fraction of trace gas in a moist air mixture at the start of simulation. If the value is a scalar, then the initial mole fraction is assumed uniform. If the value is a two-element vector, then the initial mole fraction is assumed to vary linearly between ports **A2** and **B2**, with the first element corresponding to port **A2** and the second element corresponding to port **B2**.

This parameter is ignored if the **Trace gas model** parameter in the Moist Air Properties (MA) block is set to None.

**Dependencies**

To enable this parameter, set **Initial trace gas specification** to Mole fraction.

**Relative humidity at saturation – Relative humidity point of condensation**

1 (default) | nonnegative scalar

Relative humidity point of condensation. Condensation occurs above this value. In most cases, this value is 1, that is, 100%. A value greater than 1 indicates a supersaturated vapor.

### Correlation Coefficients

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid — Correlation coefficient for thermal liquid**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid — Reynolds number exponent in correlation for thermal liquid**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for thermal liquid — Prandtl number exponent in correlation for thermal liquid**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for thermal liquid.

**a in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air — Correlation coefficient for moist air**

0.023 (default) | positive scalar

Proportionality constant in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

**b in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air — Reynolds number exponent in correlation for moist air**

0.8 (default) | positive scalar

Reynolds number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

**c in  $Nu = a \cdot Re^b \cdot Pr^c$  for moist air — Prandtl number exponent in correlation for moist air**

0.33 (default) | positive scalar

Prandtl number exponent in the correlation of Nusselt number as a function of Reynolds number and Prandtl number for moist air. The default value is based on the Colburn equation.

## Version History

Introduced in R2022a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

System-Level Condenser Evaporator (2P-MA) | System-Level Condenser Evaporator (2P-TL) | System-Level Heat Exchanger (2P-2P)

# T-junction

Hydraulic resistance of T-junction in pipe

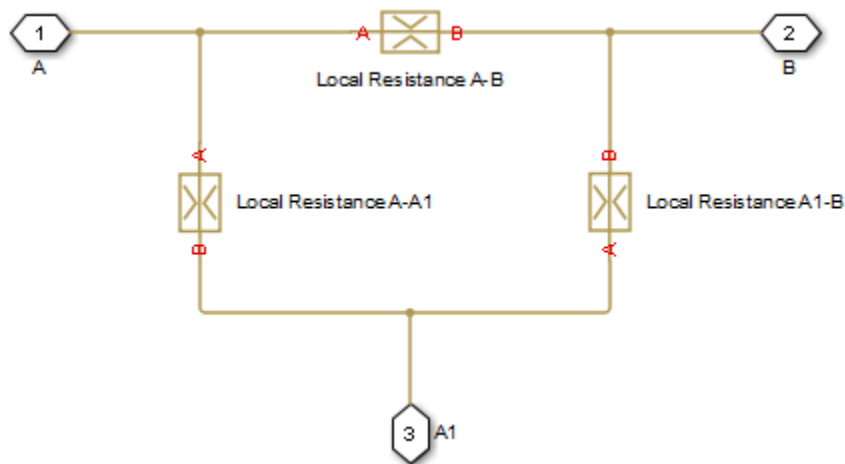


## Library

Local Hydraulic Resistances

### Description

The T-junction block represents a T-junction (wye connection) consisting, in general, of a main run and a branch merging to the main run. The junction as a hydraulic resistance is built of three Local Resistance blocks, as shown in the following diagram.



To specify pressure loss for all possible flow directions, you have to provide six pressure loss coefficients. The flow regime is checked in the underlying Local Resistance blocks by comparing the Reynolds number to the specified critical Reynolds number value, and depending on the result, the appropriate formula for pressure loss computation is used. For more information, see the reference documentation for the Local Resistance block.

The block positive direction is from port A to port B, from port A to port A1, and from port A1 to port B.

### Basic Assumptions and Limitations

- Fluid inertia is not taken into account.

## Parameters

### Geometry Tab

#### Main pipe diameter

The internal pipe diameter of the main run. The default value is 0.01 m.

#### Branch pipe diameter

The internal pipe diameter of the branch. The default value is 0.01 m.

#### Laminar transition specification

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

#### Laminar flow pressure ratio

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

#### Critical Reynolds number

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 120. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### Pressure Loss Tab

#### A-B pressure loss coefficient

The pressure loss coefficient between ports A and B when fluid flows in the direction from A to B. The default value is 1.12.

#### B-A pressure loss coefficient

The pressure loss coefficient between ports A and B when fluid flows in the direction from B to A. The default value is 1.12.

#### A-A1 pressure loss coefficient

The pressure loss coefficient between ports A and A1 when fluid flows in the direction from A to A1. The default value is 1.36.

#### A1-A pressure loss coefficient

The pressure loss coefficient between ports A and A1 when fluid flows in the direction from A1 to A. The default value is 1.65.

#### A1-B pressure loss coefficient

The pressure loss coefficient between ports A1 and B when fluid flows in the direction from A1 to B. The default value is 1.6.



**B-A1 pressure loss coefficient**

The pressure loss coefficient between ports A1 and B when fluid flows in the direction from B to A1. The default value is 1.8.

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the main run inlet.

B

Hydraulic conserving port associated with the main run outlet.

A1

Hydraulic conserving port associated with the branch inlet.

**Version History**

Introduced in R2006b

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Elbow | Gradual Area Change | Local Resistance | Pipe Bend | Sudden Area Change

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## T-Junction (IL)

Three-way junction in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings

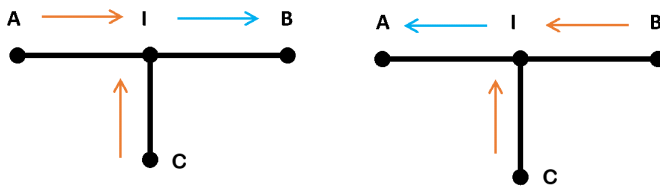


### Description

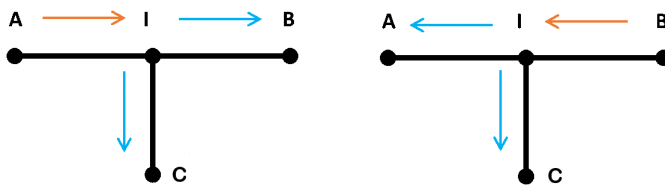
The T-Junction (IL) block models a three-way pipe junction with a branch line at port **C** connected at a 90° angle to the main pipe line, between ports **A** and **B**. You can specify a custom or standard junction type. When **Three-way junction type** is set to **Custom**, you can specify the loss coefficients of each pipe segment for converging and diverging flows. The standard model applies industry-standard loss coefficients to the momentum equations.

### Flow Direction

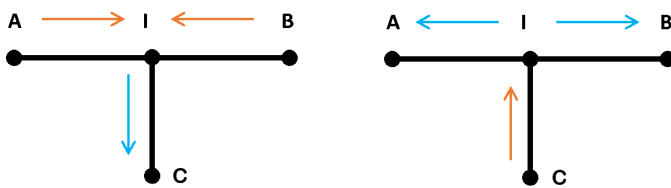
The flow is *converging* when the branch flow, the flow through port **C**, merges into the main flow. The flow is *diverging* when the branch flow splits from the main flow. The flow direction between **A** and **I**, the point where the branch meets the main, and **B** and **I** must be consistent for all loss coefficients to be applied. If they are not, as shown in the last two diagrams in the figure below, the losses in the junction are approximated with the main branch loss coefficient for converging or diverging flows.



### Converging Flows



### Diverging Flows



### Approximated Flow Losses

#### Flow Scenarios

The block uses mode charts to determine each loss coefficient for a given flow configuration. This table describes the conditions and coefficients for each operational mode.

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$K_A$	$K_B$	$K_C$
Converging to node B	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$K_{main,conv}$	0	$K_{main,conv}$
Converging to node A	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	0	$K_{main,conv}$	$K_{side,conv}$
Diverging from node A	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$K_{main,div}$	$K_{side,div}$
Diverging from node B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$K_{main,div}$	0	$K_{side,div}$
Converging to node C (branch)	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$(K_{main,conv} + K_{branch,conv})/2$	$(K_{main,conv} + K_{branch,conv})/2$	0

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$K_A$	$K_B$	$K_C$
Diverging from node C (branch)	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$(K_{main,div} + K_{branch,div})/2$	$(K_{main,div} + K_{branch,div})/2$	0
Stagnant	-	-	-	1 or last valid	1 or last valid	1 or last valid

The flow is stagnant when the mass flow rate conditions do not match any defined flow scenario. The mass flow rate threshold, which is the point at which the flow in the pipe begins to reverse direction, is calculated as:

$$\dot{m}_{thresh} = Re_c \nu \bar{\rho} \sqrt{\frac{\pi}{4} A_{min}}$$

where:

- $Re_c$  is the **Critical Reynolds number** parameter, beyond which the transitional flow regime begins.
- $\nu$  is the fluid viscosity.
- $\bar{\rho}$  is the average fluid density.
- $A_{min}$  is the smallest cross-sectional area in the pipe junction.

### Standard T-Junction

When **Three-way junction type** is set to Standard, the pipe loss coefficients,  $K_{main}$  and  $K_{side}$ , and the pipe friction factor,  $f_T$ , are calculated according to Crane [1]:

$$K_{main,div} = K_{main,conv} = 20f_{T,main}$$

$$K_{side,div} = K_{side,conv} = 60f_{T,side}$$

In contrast to the custom junction type, the standard junction loss coefficient is the same for both converging and diverging flows.  $K_A$ ,  $K_B$ , and  $K_C$  are then calculated in the same manner as custom junctions.

### PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE WITH FLOW IN ZONE OF COMPLETE TURBULENCE

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_T$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

### Friction Factor per Nominal Pipe Diameter

#### Custom T-Junction

When **Three-way junction type** is set to Custom, the pipe loss coefficient at each port,  $K$ , is calculated based on the user-defined loss parameters for converging and diverging flow and mass flow rate at each port. You must specify  $K_{main,conv}$ ,  $K_{main,div}$ ,  $K_{side,conv}$ , and  $K_{side,div}$  as the **Main branch**

**converging loss coefficient, Main branch diverging loss coefficient, Side branch converging loss coefficient, and Side branch diverging loss coefficient** parameters, respectively.

### Mass and Momentum Balance

The block conserves mass in the junction such that

$$\dot{m}_A + \dot{m}_B + \dot{m}_C = 0.$$

Flow through the pipe junction is calculated from momentum conservation equations between ports **A**, **B**, and **C**:

$$p_A - p_I = I_A + \frac{K_A}{2\bar{\rho}A_{main}^2} \dot{m}_A \sqrt{\dot{m}_A^2 + \dot{m}_{thresh}^2}$$

$$p_B - p_I = I_B + \frac{K_B}{2\bar{\rho}A_{main}^2} \dot{m}_B \sqrt{\dot{m}_B^2 + \dot{m}_{thresh}^2}$$

$$p_C - p_I = I_C + \frac{K_C}{2\bar{\rho}A_{side}^2} \dot{m}_C \sqrt{\dot{m}_C^2 + \dot{m}_{thresh}^2}$$

where  $I$  represents the fluid inertia, and

$$I_A = \ddot{m}_A \frac{\sqrt{\pi \cdot A_{side}}}{A_{main}}$$

$$I_B = \ddot{m}_B \frac{\sqrt{\pi \cdot A_{side}}}{A_{main}}$$

$$I_C = \ddot{m}_C \frac{\sqrt{\pi \cdot A_{main}}}{A_{side}}$$

$A_{main}$  is the **Main branch area (A-B)** parameter and  $A_{side}$  is the **Side branch area (A-C, B-C)** parameter.

### Energy Balance

The block balances energy such that

$$\phi_A + \phi_B + \phi_C = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.
- $\phi_C$  is the energy flow rate at port **C**.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can

come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Liquid entry or exit port.

#### **B – Liquid port**

isothermal liquid

Liquid entry or exit port.

#### **C – Liquid port**

isothermal liquid

Liquid entry or exit port.

## Parameters

#### **Main branch area (A-B) – Cross-sectional area between ports A and B**

0.01 m<sup>2</sup> (default) | positive scalar

Area of connecting pipe between ports **A** and **B**.

#### **Side branch area (A-C, B-C) – Cross-sectional area of the side branch**

0.01 m<sup>2</sup> (default) | positive scalar

Area of connecting pipe between ports **A** and **C** and between ports **B** and **C**.

#### **Three-way junction type – Junction loss coefficient type**

Standard (default) | Custom

The junction loss coefficient type. Set this parameter to Custom to specify individual diverging and converging loss coefficients for each flow path segment.

#### **Main branch converging loss coefficient – Loss coefficient between A and B for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between ports **A** and **B** for converging flow.

#### **Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

#### **Main branch diverging loss coefficient – Loss coefficient between A and B for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between ports **A** and **B** for diverging flow.

**Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

**Side branch converging loss coefficient – Branch loss coefficient for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between port C and the main line for converging flow.

**Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

**Side branch diverging loss coefficient – Branch loss coefficient for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between port C and the main line for diverging flow.

**Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the junction.

## Version History

**Introduced in R2020a****Conversion to Mode Charts**

*Behavior change in future release*

The block uses mode charts to handle the different flow configurations. Results during flow scenario transitions may be different than in previous releases. Results during flow scenario transitions are not steady state and are not necessarily accurate.

## References

[1] Crane Co. *Flow of Fluids Through Valves, Fittings, and Pipe TP-410*. Crane Co., 1981.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Area Change (IL) | Pipe Bend (IL) | Elbow (IL) | Local Resistance (IL)

**Topics**

“Mode Chart Modeling”

**External Websites**

“Mode Chart Modeling”



## T-Junction (TL)

Three-way junction in a thermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Pipes & Fittings

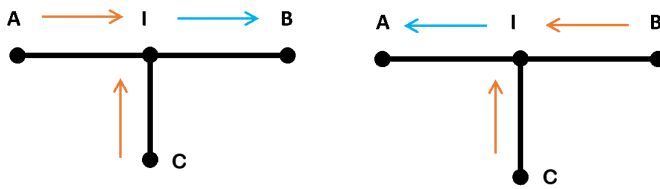


### Description

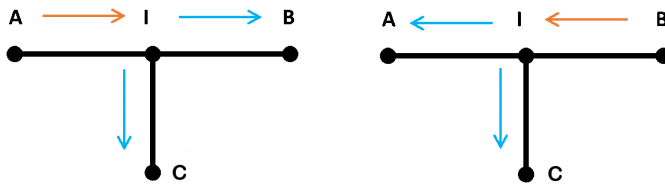
The T-Junction (TL) block represents a three-way pipe junction with a branch line at port **C** connected at a 90° angle to the main pipe line, between ports **A** and **B**. You can specify a custom or standard junction type. When **Three-way junction type** is set to **Custom**, you can specify the loss coefficients of each pipe segment for converging and diverging flows. The standard model applies industry-standard loss coefficients to the momentum equations.

### Flow Direction

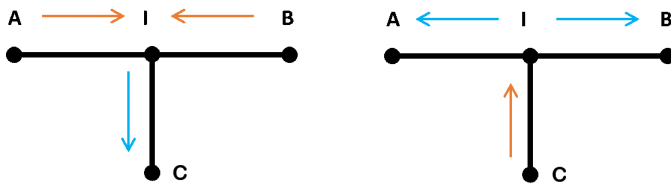
The flow is *converging* when the branch flow, the flow through port **C**, merges into the main flow. The flow is *diverging* when the branch flow splits from the main flow. The flow direction between **A** and **I**, the point where the branch meets the main, and **B** and **I** must be consistent for all loss coefficients to be applied. If they are not, as shown in the last two diagrams in the figure below, the losses in the junction are approximated with the main branch loss coefficient for converging or diverging flows.



### Converging Flows



### Diverging Flows



### Approximated Flow Losses

#### Flow Scenarios

The block uses mode charts to determine each loss coefficient for a given flow configuration. This table describes the conditions and coefficients for each operational mode.

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$K_A$	$K_B$	$K_C$
Converging to node B	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$K_{main,conv}$	0	$K_{main,conv}$
Converging to node A	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	0	$K_{main,conv}$	$K_{side,conv}$
Diverging from node A	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	0	$K_{main,div}$	$K_{side,div}$
Diverging from node B	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$K_{main,div}$	0	$K_{side,div}$
Converging to node C (branch)	$>\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$(K_{main,conv} + K_{branch,conv})/2$	$(K_{main,conv} + K_{branch,conv})/2$	0

Flow Scenario	$\dot{m}_A$	$\dot{m}_B$	$\dot{m}_C$	$K_A$	$K_B$	$K_C$
Diverging from node C (branch)	$<-\dot{m}_{thresh}$	$<-\dot{m}_{thresh}$	$>\dot{m}_{thresh}$	$(K_{main,div} + K_{branch,div})/2$	$(K_{main,div} + K_{branch,div})/2$	0
Stagnant	-	-	-	1 or last valid	1 or last valid	1 or last valid

The flow is stagnant when the mass flow rate conditions do not match any defined flow scenario. The mass flow rate threshold, which is the point at which the flow in the pipe begins to reverse direction, is calculated as:

$$\dot{m}_{thresh} = Re_c \nu \bar{\rho} \sqrt{\frac{\pi}{4} A_{min}}$$

where:

- $Re_c$  is the **Critical Reynolds number**, beyond which the transitional flow regime begins.
- $\nu$  is the fluid viscosity.
- $\bar{\rho}$  is the average fluid density.
- $A_{min}$  is the smallest cross-sectional area in the pipe junction.

### Standard T-Junction

When **Three-way junction type** is set to Standard, the pipe loss coefficients,  $K_{main}$  and  $K_{side}$ , and the pipe friction factor,  $f_T$ , are calculated according to Crane [1]:

$$K_{main,div} = K_{main,conv} = 20f_{T,main}$$

$$K_{side,div} = K_{side,conv} = 60f_{T,side}$$

In contrast to the custom junction type, the standard junction loss coefficient is the same for both converging and diverging flows.  $K_A$ ,  $K_B$ , and  $K_C$  are then calculated in the same manner as custom junctions.

### PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE WITH FLOW IN ZONE OF COMPLETE TURBULENCE

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2, 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor ( $f_f$ )	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

### Friction Factor per Nominal Pipe Diameter

#### Custom T-Junction

When **Three-way junction type** is set to Custom, the pipe loss coefficient at each port,  $K$ , is calculated based on the user-defined loss parameters for converging and diverging flow and mass flow rate at each port. You must specify  $K_{main,conv}$ ,  $K_{main,div}$ ,  $K_{side,conv}$ , and  $K_{side,div}$  as the **Main branch converging loss coefficient**, **Main branch diverging loss coefficient**, **Side branch converging loss coefficient**, and **Side branch diverging loss coefficient** parameters, respectively.

### Mass and Momentum Balance

The block conserves mass in the junction such that

$$\dot{m}_A + \dot{m}_B + \dot{m}_C = 0.$$

Flow through the pipe junction is calculated from momentum conservation equations between ports **A**, **B**, and **C**:

$$p_A - p_I = I_A + \frac{K_A}{2\bar{\rho}A_{main}^2} \dot{m}_A \sqrt{\dot{m}_A^2 + \dot{m}_{thresh}^2}$$

$$p_B - p_I = I_B + \frac{K_B}{2\bar{\rho}A_{main}^2} \dot{m}_B \sqrt{\dot{m}_B^2 + \dot{m}_{thresh}^2}$$

$$p_C - p_I = I_C + \frac{K_C}{2\bar{\rho}A_{side}^2} \dot{m}_C \sqrt{\dot{m}_C^2 + \dot{m}_{thresh}^2}$$

where  $I$  represents the fluid inertia, and

$$I_A = \ddot{m}_A \frac{\sqrt{\pi \cdot A_{side}}}{A_{main}}$$

$$I_B = \ddot{m}_B \frac{\sqrt{\pi \cdot A_{side}}}{A_{main}}$$

$$I_C = \ddot{m}_C \frac{\sqrt{\pi \cdot A_{main}}}{A_{side}}$$

$A_{main}$  is the **Main branch area (A-B)** parameter and  $A_{side}$  is the **Side branch area (A-C, B-C)** parameter.

### Energy Balance

The block balances energy such that

$$\phi_A + \phi_B + \phi_C = 0,$$

where:

- $\phi_A$  is the energy flow rate at port **A**.
- $\phi_B$  is the energy flow rate at port **B**.
- $\phi_C$  is the energy flow rate at port **C**.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Conserving

#### A – Liquid port

thermal liquid

Thermal liquid conserving port associated with the liquid entrance or exit of the junction.

#### B – Liquid port

thermal liquid

Thermal liquid conserving port associated with the liquid entrance or exit of the junction.

#### C – Liquid port

thermal liquid

Thermal liquid conserving port associated with the liquid entrance or exit of the junction.

## Parameters

### Main branch area (A-B) – Cross-sectional area between ports A and B

0.01 m<sup>2</sup> (default) | positive scalar

Area of connecting pipe between ports **A** and **B**.

### Side branch area (A-C, B-C) – Cross-sectional area of the side branch

0.01 m<sup>2</sup> (default) | positive scalar

Area of connecting pipe between ports **A** and **C** and between ports **B** and **C**.

### Three-way junction type – Junction loss coefficient type

Standard (default) | Custom

The junction loss coefficient type. Set this parameter to Custom to specify individual diverging and converging loss coefficients for each flow path segment.

### Main branch converging loss coefficient – Loss coefficient between A and B for custom junctions

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between ports **A** and **B** for converging flow.

#### Dependencies

To enable this parameter, set **Three-way junction type** to Custom.

### Main branch diverging loss coefficient – Loss coefficient between A and B for custom junctions

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between ports **A** and **B** for diverging flow.

#### Dependencies

To enable this parameter, set **Three-way junction type** to Custom.

**Side branch converging loss coefficient – Branch loss coefficient for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between port C and the main line for converging flow.

**Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

**Side branch diverging loss coefficient – Branch loss coefficient for custom junctions**

1.12 (default) | positive scalar

Loss coefficient for pressure loss calculations between port C and the main line for diverging flow.

**Dependencies**

To enable this parameter, set **Three-way junction type** to Custom.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the junction.

## Version History

**Introduced in R2022a****Conversion to Mode Charts***Behavior change in future release*

The block uses mode charts to handle the different flow configurations. Results during flow scenario transitions may be different than in previous releases. Results during flow scenario transitions are not steady state and are not necessarily accurate.

## References

[1] Crane Co. *Flow of Fluids Through Valves, Fittings, and Pipe TP-410*. Crane Co., 1981.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

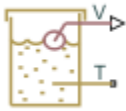
**Topics**

“Mode Chart Modeling”

# Tank

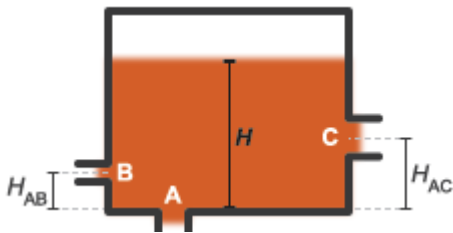
Pressurized fluid container with variable fluid level

**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Low-Pressure Blocks



## Description

The Tank block models a pressurized fluid container with a variable fluid level. The tank has an optional number of ports ranging from one to three, with each number corresponding to a block variant. The tank pressurization is fixed regardless of changes to fluid volume or fluid level. The tank is vented if the pressurization is set to zero—a setting corresponding to an internal pressure equal to atmospheric pressure.



### Tank Ports and Port Elevations

The block accounts for differences in port elevation. Hydrostatic pressure is computed separately for each port from the fluid level and port elevation. The hydrostatic pressure adds to the pressurization of the tank—increasing the port pressure as the fluid level rises. The block accounts also for minor pressure losses at the ports due to filters, fittings, and other local flow resistances. To modulate these losses, the block provides a pressure loss coefficient for each port.

### Changing the Number of Ports

To change the number of ports in the tank, use the **Modeling option** parameter to change the active block variant. Variant options include:

- **One inlet** (default) — Exposes one hydraulic conserving port, **T**.
- **Two inlets** — Exposes hydraulic conserving ports **A** and **B**.
- **Three inlets** — Exposes hydraulic conserving ports **A**, **B**, and **C**.

Port **A** in the **Two inlets** and **Three inlets** variants is a direct replacement of port **T** in the **One inlet** variant.

### Port Depth and Fluid Level

Port **T** in the **One inlet** variant—or port **A**, its replacement in the **Two inlets** and **Three inlets** variants—is by default located at the bottom of the tank. The depth of this port relative to the top of the fluid volume is equal to the fluid level—the height of the fluid volume:

$$y_{T/A} = H,$$

where:

- $y_{T/A}$  is the depth of port **T** or **A**.
- $H$  is the fluid level in the tank.

Ports **B** and **C** in the **Two inlets** and **Three inlets** variants are assumed to be located above port **A**. The depths of these ports are each computed as the difference between the fluid level and the port elevation above port **A**:

$$y_B = H - H_{AB},$$

and

$$y_C = H - H_{AC},$$

where:

- $y_B$  and  $y_C$  are the depths of ports **B**, and **C**.
- $H_{AB}$  and  $H_{AC}$  are the elevations of ports **B** and **C** above port **A**.

The fluid level,  $H$ , is computed during simulation from the instantaneous fluid volume. This calculation depends on the **Tank volume parameterization** setting. If the parameterization is set to **Constant cross-sectional area** (the default setting), the fluid level is:

$$H = \frac{V}{S},$$

where:

- $V$  is the instantaneous fluid volume in the tank.
- $S$  is the internal cross-sectional area of the tank, specified in the **Tank cross-section area** parameter.

If the **Tank volume parameterization** is set to **Tabulated data – Volume vs. level**, the fluid level is computed by interpolation or extrapolation of tabulated fluid level data specified as a function of fluid volume:

$$H = f(V)$$

The instantaneous fluid volume varies with the volumetric flow rates through the exposed ports. This volume increases if the sum of all flow rates is positive. A flow rate is positive if it is directed from the port to the interior of the tank, that is, if fluid enters the tank. The time rate of change of the fluid volume is defined as:

$$\frac{dV}{dt} = \sum_i q_i,$$



where  $q_i$  is the flow rate into the tank through the port denoted by  $i$ —**T/A**, **B**, or **C**.

### Flow Rate and Pressure Drop

The volumetric flow rate through a port is a function of the pressure drop from that port to the interior of the tank. The flow rate is positive if the pressure drop is positive—that is, if pressure is higher at the port than in the tank—and negative otherwise:

$$q_i = A_i \sqrt{\frac{2}{K_i \rho}} \frac{\Delta p_i}{(\Delta p_i^2 + p_{Cr,i}^2)^{1/4}},$$

where:

- $A_i$  is the internal cross-sectional area of the port denoted by  $i$  (**T/A**, **B**, or **C**):

$$A_i = \frac{\pi d_i^2}{4},$$

with  $d_i$  as the internal diameter of the port.

- $K_i$  is the pressure loss coefficient specified for the port.
- $\rho$  is the hydraulic fluid density.
- $\Delta p_i$  is the pressure drop from the port to the interior of the tank.
- $p_{Cr,i}$  is the critical pressure at which the flow through the port switches between laminar and turbulent.

The critical pressure at a port is computed from the critical Reynolds number, internally set to a value of 15, and from the respective port diameter. The critical pressure is modulated by the pressure loss coefficient specified for the port—with this parameter serving as a gain for the critical pressure:

$$p_{Cr,i} = K_i \frac{\rho}{2} \left( \frac{Re_{Cr} \nu}{d_i} \right),$$

where:

- $Re_{Cr}$  is the critical Reynolds number.
- $\nu$  ( $nu$ ) is the hydraulic fluid dynamic viscosity.
- $d_i$  is the internal diameter of the port denoted by  $i$ .

The pressure drop from a port to the interior of the tank is computed from the specified **Pressurization** value, the hydrostatic pressure, and the pressure at the port:

$$\Delta p_i = p_{port,i} - (p_{press} + p_{elev,i}),$$

where:

- $p_{port,i}$  is the pressure at the port denoted by  $i$ .
- $p_{press}$  is the specified tank **Pressurization** value.
- $p_{elev,i}$  is the hydrostatic pressure at the port.

The hydrostatic pressure at a port is a function of the port elevation above the bottom of the tank (zero for port **T/A**):

$$p_{elev, i} = \rho g y_i$$

where

- $g$  is the value of the gravitational acceleration at the mean elevation of the system.
- $y_i$  is the elevation of the port denoted by  $i$  relative to the bottom of the port.

### C/C++ Code Generation

This block supports code generation for real-time simulation tasks. Certain blocks and block settings may be more suitable for simulation on a real-time device. For suggestions on how to improve real-time simulation performance, use the Simulink Performance Advisor function. Suggestions include ways to reduce model complexity and decrease numerical stiffness.

In the Simulink Editor, click the **Debug** tab and select **Performance Advisor** from **Performance Advisor**. Set the **Activity** parameter to `Execute real-time application` to view suggestions specific to real-time simulation performance. Expand the **Real-Time** node in the tree view pane to select performance checks specific to Simscape products.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Ports

### Output

#### V — Fluid volume, m<sup>3</sup>

physical signal

Physical signal output port reporting the volume of fluid in the tank.

### Conserving

#### T — Tank inlet

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the tank inlet.

### Dependencies

To enable this port, set **Modeling option** to `One inlet`.

#### A — Tank inlet

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing one of multiple tank inlets.

**B – Tank inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing one of multiple tank inlets.

**Dependencies**

To enable this port, set **Modeling option** to `Two inlets` or `Three inlets`.

**C – Tank inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing one of multiple tank inlets.

**Dependencies**

To enable this port, set **Modeling option** to `Three inlets`.

**Parameters****Modeling option – Number of ports**`One inlet` | `Two inlets` | `Three inlets`

Set the number of ports for the block.

**Main****Pressurization – Gauge pressure of the tank volume**`0 Pa (default)` | scalar number in units of pressure

Gauge pressure of the tank volume. The tank pressure is held constant at this value during simulation. The default value, `0 Pa`, corresponds to a vented tank—one whose internal pressure is equal to the atmospheric pressure of the system.

**Tank volume parameterization – Choice of parameterization for the tank volume**`Constant cross-sectional area (default)` | `Tabulated data – volume vs. level`

Choice of parameterization for the tank volume. Select `Constant cross-sectional area` to compute the tank volume from the variable fluid level and a constant cross-sectional area. Select `Tabulated data – volume vs. level` to compute the tank volume by interpolation or extrapolation of tabulated data on the fluid volume at discrete fluid levels.

**Tank cross-section area – Area of the (constant) tank cross-section**`0.8 m2 (default)` | scalar number in units of area

Area of the tank cross-section, assumed constant over the allowed range of fluid levels. The block uses this parameter to compute the volume of fluid inside the tank.

**Fluid volume vector – Fluid volumes at which to specify the tank fluid levels**`16-element row vector with values ranging from 0 to 0.727 m3 (default)` | `N-element vector with elements in units of volume`

Array of fluid volumes for the 1-D lookup table used to compute the tank fluid level. The array must increase from left to right but the intervals between the array element values need not be uniform. There must be at least two elements for `Linear` interpolation and three elements for `Smooth` interpolation.

**Dependencies**

This parameter is active when the **Tank volume parameterization** parameter is set to Tabulated data – volume vs. level.

**Fluid level vector – Fluid levels corresponding to the specified fluid volumes**

16-element row vector with values ranging from 0 to 0.3 m (default) |  $N$ -element vector with elements in units of length

Array of fluid levels corresponding to the specified orifice openings. The number of elements in the array must match the number of elements in the **Opening vector** parameter.

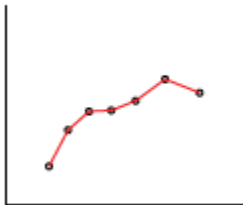
**Dependencies**

This parameter is active when the **Tank volume parameterization** parameter is set to Tabulated data – volume vs. level.

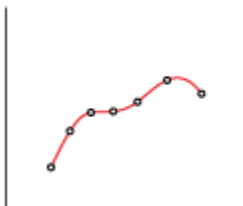
**Interpolation method – Method of computing values inside the lookup table range**

Linear (default) | Smooth

Method of computing values inside the tabulated data range. The Linear method joins adjacent data points with straight line or surface segments with generally discontinuous slope at the segment boundaries. Surface segments are used in the 2-D lookup table specified in the Pressure - flow characteristic model parameterization.



The Smooth method replaces the straight segments with curved versions that have continuous slope everywhere inside the tabulated data range. The segments form a smooth line or surface passing through all of the tabulated data points without the discontinuities in first-order derivatives characteristic of the Linear interpolation method.

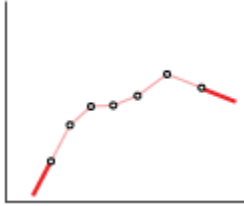
**Dependencies**

This parameter is active when the **Tank volume parameterization** parameter is set to Tabulated data – Volume vs. level.

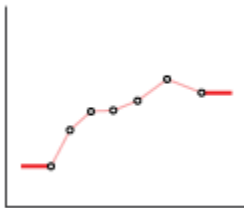
**Extrapolation method – Method of computing values outside of the lookup table range**

Linear (default) | Nearest

Method of computing values outside of the tabulated data range. The **Linear** method extends the line segment drawn between the last two data points at each end of the data range outward with a constant slope.



The **Nearest** method extends the last data point at each end of the data range outward as a horizontal line with constant value.



### Dependencies

This parameter is active when the **Tank volume parameterization** parameter is set to **Tabulated data – Volume vs. level**.

### Inlet pipeline diameter – Diameter of the tank inlet

0.02 m (default) | scalar number in units of length

Diameter of the tank inlet. The tank has a single port when this parameter is exposed.

### Dependencies

This parameter is active when the block variant is set to **One inlet**.

### Port A/B/C pipeline diameter – Diameter of tank port A/B/C

0.02 m (default) | scalar number in units of length

Diameter of tank port **A/B/C**.

### Dependencies

This parameter is active when the block variant is set to **Two inlets** or **Three inlets**.

### Pipeline pressure loss coefficient – Coefficient used to account for pressure loss at the inlet

1.2 (default) | unitless scalar number

Empirical coefficient used to account for pressure losses at the tank inlet. This parameter must be greater than zero. The block has a single port when this parameter is exposed.

**Dependencies**

This parameter is active when the block variant is set to `One inlet`.

**Port A/B/C pressure loss coefficient — Coefficient used to account for pressure loss at port A/BC**

1.2 (default) | unitless scalar number

Empirical coefficient used to account for pressure losses at port **A/B/C**. This parameter must be greater than zero.

**Dependencies**

This parameter is active when the block variant is set to `Two inlets` or `Three inlets`.

**Port B/C height above port A — Elevation of port B/C above port A**

0.8 m (default) | scalar number in units of length

Elevation of port **B/C** above port **A**. The block uses this parameter to account for differences in port elevation.

**Dependencies**

This parameter is active when the block variant is set to `Two inlets` or `Three inlets`.

**Acceleration due to gravity — Gravitational acceleration constant**

9.80665 m/s<sup>2</sup> (default) | scalar number in units of acceleration

Gravitational acceleration constant at the mean elevation of the hydraulic system. Changes in gravitational acceleration are assumed negligible over the height of the system.

**Minimum level of fluid — Lowest fluid level allowed during simulation**

1e-3 m (default) | scalar number in units of length

Lowest fluid level allowed during simulation. The block triggers a simulation warning if the fluid level falls below the specified value.

**Check if fluid level violating minimum valid condition — Simulation warning mode for minimum valid fluid level**

None (default) | `Warning`

Simulation warning mode for invalid fluid levels in the tank. Select `Warning` to be notified when the fluid level falls below a minimum specified value.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

`Constant Head Tank` | `Reservoir`

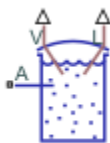
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Tank (IL)

Tank in an isothermal liquid system

**Library:** Simscape / Fluids / Isothermal Liquid / Tanks & Accumulators



### Description

The Tank (IL) block models a container with up to six input ports, **A** through **F**, within an isothermal liquid system. The tank outputs fluid volume at port **V** and fluid level at port **L** as physical signals. The block models the hydrostatic pressure difference between the liquid surface and the inlet height level. The tank can be pressurized to a constant, user-specified value or to atmospheric pressure.

### Fluid Volume

The volume of fluid in the tank is determined from the total mass flow into the tank:

$$V = \frac{M}{\rho},$$

where:

- $M$  is the total mass in the tank supplied by all ports.
- $\rho$  is the fluid density.

Due to the constant pressure in the tank, the liquid volume inside the tank changes based on mass flow rate. Note that the converse is true for pipes, where pressure is a function of fixed fluid volumes.

If the tank fluid volume exceeds the specified capacity of the tank, you can choose to be notified. Set the **Liquid volume above max capacity** parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

### Fluid Level

If **Tank volume parameterization** is set to **Constant cross-section area**, the fluid level in the tank is determined from the fluid volume  $V$ , due to the constant cross-sectional area of the tank. Otherwise, the fluid level can be specified as tabulated data in the **Tabulated data - volume vs. level** option.

When the level in the tank falls below the inlet height, the assumption that fluid entirely fills the volume of the connecting blocks may not be valid. Connections to a Pipe (IL) block, which is based on this assumption, may in this case return unphysical results. If you expect to model tank fluid levels below tank inlet height(s), connect the Tank (IL) block to your system with a Partially Filled Pipe (IL) block instead.

Like the **Liquid volume above max capacity** parameter, you can be notified if the tank fluid level falls below the height of the inlet port(s) during your simulation by changing the **Liquid level below inlet height** parameter setting.

### Mass Flow Rate

If you have more than one port enabled, the equations below apply to each port. The mass flow rate at the inlet port is:

$$\dot{m}_{port} = A_{port} \frac{\sqrt{2\rho}}{\sqrt{\zeta}} \frac{\Delta p_{port}}{[\Delta p_{port}^2 + \Delta p_{port,crit}^2]^{1/4}},$$

where:

- $A_{port}$  is the **Inlet cross-sectional area**.
- $\rho$  is the fluid density.
- $\zeta$  is the **Inlet pressure loss coefficient**.

The inlet pressure difference due to inlet losses is:

$$\Delta p_{port} = p_{port} - (P + \Delta p_{elev, port}),$$

where:

- $p_{port}$  is the pressure at the inlet port.
- $P$  is the **Tank pressurization** if the **Pressurization specification** parameter is set to **Specified pressure**. Otherwise,  $P$  is the atmospheric pressure.
- $\Delta p_{elev, port}$  is the hydrostatic pressure difference at the specified port **Inlet height**:  
 $\Delta p_{elev, port} = \rho g L$ , where  $L$  is either the difference in height between the fluid level and the inlet height or zero, whichever is larger.

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the *critical Reynolds number*,  $Re_{crit}$ , which is the point of transition between laminar and turbulent flow in the fluid:

$$\Delta p_{crit} = \frac{\pi \rho P R_{loss}}{8 A_{port}} (\nu Re_{crit})^2,$$

where  $\nu$  is the fluid kinematic viscosity.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.



## Ports

### Conserving

#### **A – Liquid port**

isothermal liquid

Tank inlet.

#### **B – Liquid port**

isothermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 2, 3, 4, 5, or 6.

#### **C – Liquid port**

isothermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 3, 4, 5, or 6.

#### **D – Liquid port**

isothermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 4, 5, or 6.

#### **E – Liquid port**

isothermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 5 or 6.

#### **F – Liquid port**

isothermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 6.

### Output

#### **V – Liquid volume, m<sup>3</sup>**

physical signal

Liquid volume inside the tank in  $m^3$ , specified as a physical signal.

**L – Liquid level, m**

physical signal

Liquid level inside the tank in m, specified as a physical signal.

**Parameters****Number of inlets – Number of inlet ports**

1 (default) | positive integer between 1 and 6

Number of inlet ports. Setting this parameter to 2 or more exposes additional input ports.

**Pressurization specification – Tank pressure**

Atmospheric pressure (default) | Specified pressure

Specifies a constant tank pressure. You can define a non-atmospheric pressure by selecting Specified pressure and defining the value in **Tank pressurization**.

**Tank pressurization – User-defined tank pressure**

0.101325 MPa (default) | positive scalar

User-defined tank pressure.

**Tank volume parameterization – Tank area characteristics**

Constant cross-section area (default) | Tabulated data - volume vs. level

Specifies tank area characteristics. This parameter is used to determine the fluid level in the tank. If you would like to model a tank with a variable cross-sectional area, you can provide data for tank volume and fluid level in the Tabulated data - volume vs. level option.

**Tank cross-sectional area – Tank cross-sectional area**

1  $m^2$  (default) | positive scalar

Tank cross-sectional area.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Constant cross-section area.

**Liquid level vector – Vector of tank fluid levels**

[0, 3, 5] m (default) | 1-by- $n$  vector

Vector of tank fluid levels for the tabular parameterization of a non-constant tank area. The values in this vector correspond one-to-one to values in the **Volumetric flow rate vector** parameter. Its elements are listed in ascending order. The elements must be positive and the first element must be 0.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Tabulated data - volume vs. level.

**Liquid volume vector – Vector of tank fluid volumes**[0, 4, 6] m<sup>3</sup> (default) | 1-by-*n* vector

Vector of tank fluid volumes for the tabular parameterization of a non-constant tank area. The values in this vector correspond one-to-one to values in the **Liquid level vector** parameter. Its elements are listed in ascending order. The elements must be positive and the first element must be 0.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Tabulated data - volume vs. level.

**Inlet height – Height of inlet port**

0.1 m (default) | positive scalar

Height of inlet port. The value must be greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 1.

**Inlet cross-sectional area – Cross-sectional area of the port inlet**0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the port inlet. This value must be greater than 0.

**Inlet pressure loss coefficient – Loss coefficient for pressure at inlet port**

1.2 (default) | positive scalar

Loss coefficient for pressure at inlet port. This value is used for calculating the hydrostatic pressure at the inlet and determining the fluid level minimum conditions.

**Height vector for inlets A and B – Vector of port heights for multiple enabled ports**[.1, .1] m (default) | 1-by-*n* vector

Vector of port heights for multiple enabled ports. If you have two or more ports enabled, the **Inlet height** parameter becomes a vector of values that correspond to the height of each inlet port, starting with port **A**. The parameter name and vector length depend on the value of the **Number of inlets** parameter. The default height for each inlet is .1 m. Each element of this vector must be greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 2, 3, 4, 5, or 6.

**Cross-sectional area vector for inlets A and B – Vector of inlet areas for two enabled ports**[.01, .01] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of cross-sectional areas for multiple enabled ports. If you have two or more ports enabled, the **Inlet cross-sectional area** parameter becomes a vector of values that correspond to the cross-sectional area of each inlet, starting with port **A**. The parameter name will include all enabled ports. Each element of this vector must be greater than 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 2, 3, 4, 5, or 6.

**Pressure loss coefficient vector for inlets A and B — Vector of pressure loss coefficients for tank inlets**[1.2, 1.2] (default) | 1-by-*n* vector

Vector of pressure loss coefficients for multiple enabled ports. If you have two or more ports enabled, the **Pressure loss coefficient** parameter becomes a vector of values corresponding to the loss coefficient for each inlet port, starting with port **A**. The parameter name will include all enabled ports. Each element of this vector must be greater than 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 2, 3, 4, 5, or 6.

**Liquid level below inlet height — Whether to be notified of low tank levels**

Error (default) | None | Warning

Whether to be notified if the tank fluid level falls below the port inlet height during simulation. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

**Liquid volume above max capacity — Whether to be notified of high tank volume**

None (default) | Warning | Error

Whether to be notified if the tank fluid volume rises above the tank maximum capacity during simulation. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

**Maximum tank capacity — Fill limit of the tank**10 m<sup>3</sup> (default) | positive scalar

Fill limit of the tank.

**Dependencies**

To enable this parameter, set **Liquid volume above max capacity** to either:

- Warning
- Error

**Gravitational acceleration — Acceleration of gravity constant**9.81 m/s<sup>2</sup> (default) | positive scalar

Constant for the acceleration of gravity.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

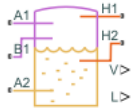
**See Also**

Partially Filled Pipe (IL) | Partially Filled Vertical Pipe LP | Gas-Charged Accumulator (IL) | Spring-Loaded Accumulator (IL)

## Tank (G-TL)

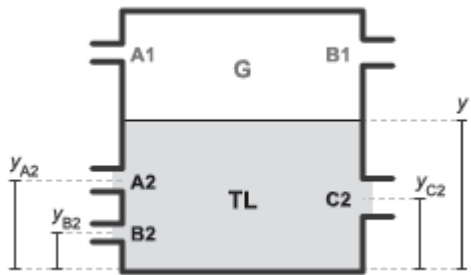
Pressurized tank with variable gas and thermal liquid volumes

**Library:** Simscape / Fluids / Fluid Network Interfaces / Tanks & Accumulators



### Description

The Tank (G-TL) block models the accumulation of mass and energy in a chamber with separate gas and thermal liquid volumes. The total fluid volume is fixed but the individual gas and thermal liquid volumes are free to vary. Two gas ports allow for gas flow and a variable number of thermal liquid ports, ranging from one to three, allow for thermal liquid flow. The thermal liquid ports can be at different elevations.



### Tank Inlets and Inlet Heights ( $y$ )

The tank is pressurized but the pressurization is not fixed. It changes during simulation with the pressure in the gas volume. It rises when the pressure of the gas volume rises and it falls when the pressure of the gas volume falls. The thermal liquid volume is assumed to be at equilibrium with the gas volume and its pressure is therefore the same as that of the gas.

The fluid volumes can exchange energy with other fluid components and with the environment but not with each other. The fluid volumes behave as if they were isolated from each other by an insulated membrane. Energy exchanges with other components occur through gas or thermal liquid ports, while exchanges with the environment occur, strictly in the form of heat, through thermal ports.

Use this block to model components such as drain tanks, in which water condensed from a compressed gas system is trapped at the bottom by gravity and expelled through a drain outlet. Note, however, that neither gas nor thermal liquid domains capture the effects of phase change—and therefore that this block cannot capture the effects of condensation.

### Inlet Variants

The number of thermal liquid ports depends on the block variant that is active. To view or change the active variant, use the **Modeling option** parameter. The `One inlet` variant exposes thermal liquid port **A2**, the `Two inlets` variant adds port **B2**, and the `Three inlets` variant adds port **C2**.

## Fluid Volumes

The total volume of the tank is equal to the sum of the gas and thermal liquid volumes that it contains:

$$V_T = V_L + V_G,$$

where  $V$  is volume and T, L, and G stand for *total*, *liquid*, and *gas*. Because the total volume is fixed, the time rate of change of the gas volume must be the reverse of that measured for the thermal liquid volume:

$$\dot{V}_G = -\dot{V}_L.$$

The time rate of change of the thermal liquid volume is calculated by differentiating the expression:

$$M_L = \rho_L V_L,$$

where  $M$  is mass and  $\rho$  is density. The differentiation gives the mass flow rate into the thermal liquid volume:

$$\dot{M}_L = V_L \dot{\rho}_L + \dot{V}_L \rho_L,$$

The time rate of change of the thermal liquid density is:

$$\dot{\rho}_L = \frac{\rho_L}{\beta_L} \dot{p}_L - \alpha_L \rho_L \dot{T}_L,$$

where:

- $\beta$  is the isothermal bulk modulus.
- $\alpha$  is the isobaric thermal expansion coefficient.
- $p$  is the fluid pressure.
- $T$  is the fluid temperature.

Rearranging terms gives the rate of change of the thermal liquid volume and, by extension, of the gas volume:

$$\dot{V}_G = -\dot{V}_L \approx V_L \left( \frac{\dot{p}_L}{\beta_L} - \alpha_L \dot{T}_L \right) - \frac{\dot{M}_L}{\rho_L}$$

## Mass Balance

The rate of mass accumulation in each fluid volume is equal to the net mass flow rate into that fluid volume. In the thermal liquid volume:

$$\dot{M}_L = \sum_{i=A2, B2, C2} \dot{m}_i,$$

where  $M_L$  is the rate of mass accumulation in the thermal liquid volume and  $\dot{m}_i$  are the individual mass flow rates into that volume through the thermal liquid ports (**A2**, **B2**, and **C2** in the case of the Three inlets variant). The rate of mass accumulation contains contributions from pressure, temperature, and volume change:

$$\dot{M}_L = V_L \left( \frac{\rho_L}{\beta_L} \dot{p}_G - \alpha_L \rho_L \dot{T}_L \right) + \dot{V}_L \rho_L,$$

where the pressure of the thermal liquid volume is by definition equal to the pressure of the gas volume and the equation is therefore written in terms of the gas pressure. In the gas volume:

$$\dot{M}_G = \sum_{i = A1, B1} \dot{m}_i,$$

where  $M_G$  is the rate of mass accumulation in the gas volume and  $\dot{m}_i$  are the individual mass flow rates into that volume through the gas ports (**A2** and **B2**). As with the thermal liquid volume, the rate of mass accumulation contains contributions from pressure, temperature, and volume change:

$$\dot{M}_G = \left. \frac{dM}{dp} \right|_G \dot{p}_G + \left. \frac{dM}{dT} \right|_G \dot{T}_G + \dot{V}_G \rho_G,$$

where the pressure and temperature derivatives depend on the type of gas specified in the Gas Properties (G) block. The derivatives are defined in the equations section of the Translational Mechanical Converter (G) block reference page. Replacing  $V_G$  with the expression previously obtained for this variable and combining the two expressions for  $M_G$ :

$$\left. \frac{dM}{dp} \right|_G \dot{p}_G + \left. \frac{dM}{dT} \right|_G \dot{T}_G + \left[ V_L \left( \frac{\dot{p}_G}{\beta_L} - \alpha_L \dot{T}_L \right) - \frac{\dot{M}_L}{\rho_L} \right] \rho_G = \sum_{i = A1, B1} \dot{m}_i.$$

Rearranging terms gives the final expression for the mass balance in the gas volume:

$$\dot{p}_G \left( \left. \frac{dM}{dp} \right|_G + \frac{\rho_G V_L}{\beta_L} \right) + \left( \dot{T}_G \left. \frac{dM}{dT} \right|_G - \dot{T}_L \rho_G V_L \alpha_L \right) = \sum_{i = A1, B1} \dot{m}_i + \frac{\rho_G}{\rho_L} \sum_{i = A2, B2, C2} \dot{m}_i,$$

where  $\dot{M}_L$  has been replaced with the summation of the mass flow rates into the thermal liquid volume.

### Energy Balance

The rate of energy accumulation in each fluid volume is the sum of the energy flow rates through the fluid inlets, the heat flow rate through the corresponding thermal port, and the energy flow rate due to volume changes. For the gas volume:

$$\dot{p}_G \left( \left. \frac{dU}{dp} \right|_G + \rho_G h_G \frac{V_L}{\beta_L} \right) + \left( \dot{T}_G \left. \frac{dU}{dT} \right|_G - \dot{T}_L \rho_G h_G V_L \alpha_L \right) = Q_{H1} + \sum_{i = A1, B1} \phi_i + \frac{\rho_G}{\rho_L} h_G \sum_{i = A2, B2, C2} \dot{m}_i,$$

where:

- $U$  is the total energy of the fluid volume.
- $h$  is the fluid enthalpy.
- $Q$  is the heat flow rate through the thermal port.
- $\phi_i$  are the energy flow rates through the fluid inlets.

As before, the pressure and temperature derivatives depend on the type of gas specified in the Gas Properties (G) block. See the equations section of the Translational Mechanical Converter (G) block reference page for their definitions. For the thermal liquid volume:

$$\dot{p}_L \left. \frac{dU}{dp} \right|_L + \dot{T}_L \left. \frac{dU}{dT} \right|_L = Q_{H2} + \sum_{i = A2, B2, C2} \phi_i + \sum_{i = A2, B2, C2} \dot{m}_i g(y(i) - y) - h_L \sum_{i = A2, B2, C2} \dot{m}_i,$$

where the pressure derivative is:



$$\left. \frac{dU}{dp} \right|_L = -T_L \alpha_L V_L,$$

and the temperature derivative is:

$$\left. \frac{dU}{dT} \right|_L = c_{p,L} \rho_L V_L,$$

in which  $c_p$  is the isobaric specific heat of the thermal liquid inside the tank.

### Momentum Balance

Flow resistance due to friction or other causes is ignored in both fluid volumes. The effect of elevation on inlet pressure is also ignored, but only on the gas side. The gas inlet pressures are therefore equal to each other and to the internal pressure of the gas volume:

$$p_{A1} = p_{B1} = p_G.$$

The thermal liquid inlet pressures are each a function of inlet depth. The internal pressure of the thermal liquid volume is equal to that of the gas volume ( $p_L = p_G$ ). Including the dynamic pressures ( $p_{i,dyn}$ ) at the inlets:

$$p_i + p_{i,dyn} = p_G + \rho_L (y - y_i) g,$$

where  $y$  is the elevation of the thermal liquid surface,  $y_i$  is the elevation of the thermal liquid inlet, and  $g$  is the gravitational constant. The term  $(y - y_i)$  gives the depth of the thermal liquid inlet with respect to the gas-thermal liquid boundary. The dynamic pressure at each thermal liquid inlet depends on the direction of flow at that inlet:

$$p_{i,dyn} = \begin{cases} \frac{1}{2} \rho_i v_i^2, & \text{if } \dot{m}_i < 0 \\ 0, & \text{if } \dot{m}_i \geq 0 \end{cases}$$

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables” and “Initial Conditions for Blocks with Finite Gas Volume”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- Fluid momentum is lost at the tank inlet due to the sudden expansion into the tank volume.

### Ports

#### Output

**V** — Thermal liquid volume, m<sup>3</sup>

physical signal

Physical signal output port reporting the volume of thermal liquid in the tank.

**L — Thermal liquid level, m**

physical signal

Physical signal output port reporting the height of the thermal liquid volume relative to the bottom of the tank.

**Conserving****A1 — Gas inlet**

gas

Opening through which gas can flow into or out of the tank.

**B1 — Gas inlet**

gas

Opening through which gas can flow into or out of the tank.

**A2 — Thermal liquid inlet**

thermal liquid

Opening through which thermal liquid can flow into or out of the tank.

**B2 — Thermal liquid inlet**

thermal liquid

Opening through which thermal liquid can flow into or out of the tank.

**Dependencies**

To enable this port, set **Modeling option** to `Two inlets` or `Three inlets`.

**C2 — Thermal liquid inlet**

thermal liquid

Opening through which thermal liquid can flow into or out of the tank.

**Dependencies**

To enable this port, set **Modeling option** to `Three inlets`.

**Parameters****Modeling option — Number of thermal liquid ports**

`One inlet` | `Two inlets` | `Three inlets`

Set the number of thermal liquid ports for the block.

**Main****Total tank volume — Combined gas and thermal liquid volume**

`10 m^3` (default) | positive scalar with units of volume

Aggregate volume of the gas and thermal liquid portions of the tank.

**Tank volume parameterization – Choice of parameterization for the thermal liquid volume**

Constant cross-sectional area (default) | Tabulated data – volume vs. level

Choice of parameterization for the thermal liquid volume. Select **Tabulated data – volume vs. level** to compute the thermal liquid volume by interpolation or extrapolation of tabulated data.

**Tank cross-sectional area – Area of the (constant) tank cross-section**1 m<sup>2</sup> (default) | scalar number in units of area

Area of the tank cross-section, assumed constant over the allowed range of fluid levels. The block uses this parameter to compute the volume of thermal liquid inside the tank.

**Liquid level vector – Thermal liquid levels at which to specify the thermal liquid volume**

[0, 3, 5] m (default) | scalar number in units of length

Vector of thermal liquid levels at which to specify the thermal liquid volume in the tank. The block uses this vector to construct a one-way lookup table for the thermal liquid volume as a function of the thermal liquid level.

**Dependencies**

This parameter is active when the **Tank volume parameterization** parameter is set to **Tabulated data - volume vs. level**.

**Liquid volume vector – Thermal liquid volume corresponding to the specified thermal liquid levels**[0, 4, 6] m<sup>3</sup> (default) | scalar number in units of volume

Vector of thermal liquid volumes corresponding to the values specified in the **Liquid level vector** parameter. The block uses this vector to construct a one-way lookup table for the thermal liquid volume as a function of the thermal liquid level.

**Dependencies**

This parameter is active when the **Tank volume parameterization** parameter is set to **Tabulated data - volume vs. level**.

**Inlet height at port A2 – Height of the thermal liquid inlet**

0.1 m (default) | positive scalar with units of length

Height of the thermal liquid inlet.

**Dependencies**

This parameter is active when the block variant is set to **One inlet**.

**Height vector for inlets A2 and B2 – Heights of the thermal liquid inlets**

[.1, .1] m (default) | vector with number of elements equal to the number of thermal liquid ports

Vector of heights of the thermal liquid ports relative to the bottom of the tank.

**Dependencies**

This parameter is active when the block variant is set to **Two inlets**.

**Height vector for inlets A2, B2, and C2 — Heights of the thermal liquid inlets**

[.1, .1, .1] m (default) | vector with number of elements equal to the number of thermal liquid ports

Vector of heights of the thermal liquid ports relative to the bottom of the tank.

**Dependencies**

This parameter is active when the block variant is set to Three inlets.

**Cross-sectional area vector for inlets A1 and B1 — Flow areas of the gas inlets**

[.01, .01] m<sup>2</sup> (default) | vector with two elements

Vector with flow areas of the gas inlets.

**Cross-sectional area at port A2 — Flow area of the thermal liquid inlet**

0.01 m<sup>2</sup> (default) | positive scalar with units of area

Flow area of the thermal liquid inlet.

**Dependencies**

This parameter is active when the block variant is set to One inlet.

**Cross-sectional area vector for inlets A2 and B2 — Flow areas of the thermal liquid inlets**

[0.01, 0.01] m<sup>2</sup> (default) | vector with number of elements equal to the number of thermal liquid ports

Flow areas of the thermal liquid inlets.

**Dependencies**

This parameter is active when the block variant is set to Two inlets.

**Cross-sectional area vector for inlets A2, B2, and C2 — Flow areas of the thermal liquid inlets**

[0.01, 0.01, 0.01] m<sup>2</sup> (default) | vector with number of elements equal to the number of thermal liquid ports

Flow areas of the thermal liquid inlets.

**Dependencies**

This parameter is active when the block variant is set to Three inlets.

**Gravitational acceleration — Gravitational acceleration constant**

9.81 m/s<sup>2</sup> (default) | scalar number with units of length/time<sup>2</sup>

Value of the gravitational acceleration at the elevation of the tank. This constant is assumed constant over the height of the tank.

## Version History

Introduced in R2017b

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

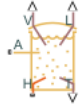
### **See Also**

Tank (TL) | Tank

## Tank (TL)

Thermal liquid container with variable fluid volume

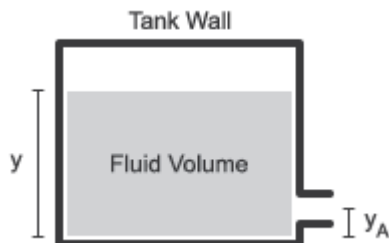
**Library:** Simscape / Fluids / Thermal Liquid / Tanks & Accumulators



### Description

The Tank (TL) block models a thermal liquid container with a variable fluid volume. The absolute pressure of the tank fluid volume is assumed constant and equal to the value specified in the block dialog box. In the special case that the tank pressurization is equal to atmospheric pressure, the block represents a vented tank.

The tank can exchange energy with its surroundings, allowing its internal temperature and pressure to evolve over time. Heat transfer occurs via convection, as liquid enters or exits the chamber, and conduction, as thermal energy flows through the tank walls and the liquid itself at the tank inlets.



### Tank Schematic

The tank can have up to six input ports, **A** through **F**. The pressure at the tank inlets is the sum of the constant tank pressurization specified in the block dialog box and the hydrostatic pressure due to the inlet height.

The tank model accounts for heat transfer through the tank wall, associated with thermal conserving port **H**. The temperature defined at this port is the temperature of the tank fluid volume.

### Tank Volume

The tank fluid volume is computed from the total fluid mass at each time step:

$$V = \frac{m}{\rho},$$

where:

- $V$  is the tank fluid volume.
- $m$  is the tank fluid mass.
- $\rho$  is the tank fluid density.

### Mass Balance

The mass conservation equation in the tank fluid volume is

$$\dot{m} = \dot{m}_A,$$

where:

- $\dot{m}$  is the net mass flow rate into the tank.
- $\dot{m}_A$  is the mass flow rate into the tank fluid volume through the inlet **A**.

### Momentum Balance

The momentum conservation equation in the tank fluid volume is

$$p_A + p_{dyn} = p_{Ref} + \rho g(y - y_A),$$

where:

- $p_A$  is the fluid pressure at inlet **A**.
- $p_{Ref}$  is the constant tank pressurization.
- $p_{dyn}$  is the dynamic pressure:

$$p_{dyn} = \begin{cases} 0, & \dot{m}_A \geq 0 \\ \frac{\dot{m}_A^2}{2\rho_A S_A^2}, & \dot{m}_A < 0 \end{cases}$$

- $\rho_A$  is the liquid density at port **A**.
- $S_A$  is the tank inlet area.
- $g$  is the gravitational constant.
- $y$  is the tank level, or height, relative to the tank bottom.
- $y_A$  is the tank inlet elevation relative to the tank bottom.

### Energy Balance

The energy conservation equation in the tank fluid volume is

$$m(C_p - h\alpha)\dot{T} = \Phi_A - \dot{m}_A h + Q,$$

where:

- $C_p$  is the fluid thermal capacity.
- $\alpha$  is the fluid isobaric bulk modulus.
- $T$  is the fluid temperature.
- $\Phi_A$  is the energy flow rate into the tank through port **A**.
- $h$  is the fluid enthalpy.
- $Q$  is the thermal energy flow rate into the tank through port **H**.

## Assumptions and Limitations

- The tank pressure is constant and uniform throughout the tank volume. The tank elevation head affects only the inlet pressure calculations.
- Fluid momentum is lost at the tank inlet due to the sudden expansion into the tank volume.

## Ports

### Conserving

#### **A – Liquid port**

thermal liquid

Tank inlet.

#### **B – Liquid port**

thermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 2, 3, 4, 5, or 6.

#### **C – Liquid port**

thermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 3, 4, 5, or 6.

#### **D – Liquid port**

thermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 4, 5, or 6.

#### **E – Liquid port**

thermal liquid

Optional tank inlet.

#### **Dependencies**

To enable this port, set **Number of inlets** to 5, or 6.

#### **F – Liquid port**

thermal liquid

Optional tank inlet.



**Dependencies**

To enable this port, set **Number of inlets** to 6.

**H — Heat transfer**

thermal liquid

Heat transfer at the tank wall.

**Output****V — Liquid volume, m<sup>3</sup>**

physical signal

Liquid volume inside the tank in m<sup>3</sup>, specified as a physical signal.

**L — Liquid level, m**

physical signal

Liquid level inside the tank in m, specified as a physical signal.

**T — Fluid temperature, K**

physical signal

Tank fluid temperature in K, specified as a physical signal.

**Parameters****Number of inlets — Number of inlet ports**

1 (default) | 2 | 3 | 4 | 5 | 6

Number of inlet ports. Setting this parameter to 2 or more exposes additional input ports.

**Pressurization specification — Tank pressure**

Atmospheric pressure (default) | Specified pressure

Specifies a constant tank pressure. You can define a non-atmospheric pressure by selecting **Specified pressure** and defining the value in **Tank pressurization**.

**Tank pressurization — User-defined tank pressure**

0.101325 MPa (default) | positive scalar

User-defined tank pressure.

**Tank volume parameterization — Tank area characteristics**

Constant cross-section area (default) | Tabulated data - volume vs. level

Specifies tank area characteristics. This parameter is used to determine the fluid level in the tank. If you would like to model a tank with a variable cross-sectional area, you can provide data for tank volume and fluid level in the **Tabulated data - volume vs. level** option.

**Tank cross-sectional area — Tank cross-sectional area**

1 m<sup>2</sup> (default) | positive scalar

Tank cross-sectional area.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Constant cross-section area.

**Liquid level vector — Vector of tank fluid levels**

[0, 3, 5] m (default) | 1-by-*n* vector

Vector of tank fluid levels for the tabular parameterization of a non-constant tank area. The values in this vector correspond one-to-one to values in the **Volumetric flow rate vector** parameter. Its elements are listed in ascending order. The elements must be positive and the first element must be 0.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Tabulated data - volume vs. level.

**Liquid volume vector — Vector of tank fluid levels**

[0, 4, 6] m<sup>3</sup> (default) | 1-by-*n* vector

Vector of tank fluid levels for the tabular parameterization of a non-constant tank area. The values in this vector correspond one-to-one to values in the **Volumetric flow rate vector** parameter. Its elements are listed in ascending order. The elements must be positive and the first element must be 0.

**Dependencies**

To enable this parameter, set **Tank volume parameterization** to Tabulated data - volume vs. level.

**Inlet height — Height of inlet port**

0.1 m (default) | positive scalar

Height of inlet port. The value must be greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 1.

**Inlet cross-sectional area — Cross-sectional area of the port inlet**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the port inlet. This value must be greater than 0.

**Height vector for inlets A and B — Vector of port heights for multiple enabled ports**

[.1, .1] m (default) | 1-by-*n* vector

Vector of port heights for multiple enabled ports. If you have two or more ports enabled, the **Inlet height** parameter becomes a vector of values that correspond to the height of each inlet port, starting with port **A**. The parameter name and vector length depend on the value of the **Number of inlets** parameter. The default height for each inlet is .1 m. Each element of this vector must be greater than or equal to 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 2, 3, 4, 5, or 6.

**Cross-sectional area vector for inlets A and B — Vector of inlet areas for two enabled ports**[.01, .01] m<sup>2</sup> (default) | 1-by-*n* vector

Vector of cross-sectional areas for multiple enabled ports. If you have two or more ports enabled, the **Inlet cross-sectional area** parameter becomes a vector of values that correspond to the cross-sectional area of each inlet, starting with port **A**. The parameter name will include all enabled ports. Each element of this vector must be greater than 0.

**Dependencies**

To enable this parameter, set **Number of inlets** to 2, 3, 4, 5, or 6.

**Liquid level below inlet height — Whether to be notified of low tank levels**

Error (default) | Warning | None

Whether to be notified if the tank fluid level falls below the port inlet height during simulation. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

**Liquid volume above max capacity — Whether to be notified of high tank volume**

None (default) | Warning | Error

Whether to be notified if the tank fluid volume rises above the tank maximum capacity during simulation. Set this parameter to **Warning** if you would like to receive a warning when this occurs during simulation. Set the parameter to **Error** if you would like the simulation to stop when this occurs.

**Maximum tank capacity — Fill limit of the tank**10 m<sup>3</sup> (default) | positive scalar

Fill limit of the tank.

**Dependencies**

To enable this parameter, set **Liquid volume above max capacity** to either:

- Warning
- Error

**Gravitational acceleration — Acceleration of gravity constant**9.81 m/s<sup>2</sup> (default) | positive scalar

Constant for the acceleration of gravity.

## Version History

Introduced in R2016a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Gas-Charged Accumulator (TL)

# Temperature Control Valve (G)

Temperature control valve in a gas network

**Library:** Simscape / Fluids / Gas / Valves & Orifices / Flow Control Valves



## Description

The Temperature Control Valve (G) block represents an orifice with a thermostat as a flow control mechanism. The thermostat contains a temperature sensor and an opening mechanism. The sensor is at the inlet and responds with a slight delay, captured by a first-order time lag, to variations in temperature.

When the sensor reads a temperature in excess of a preset activation value, the opening mechanism actuates and the valve begins to open or close, depending on the operation mode specified by the **Valve operation** parameter. The change in opening area continues up to the limit of the temperature range of the valve, beyond which the opening area is a constant. Within the temperature range, the opening area is a linear function of temperature.

The flow can be laminar or turbulent, and it can reach up to sonic speeds. The maximum velocity happens at the throat of the valve where the flow is narrowest and fastest. The flow chokes and the velocity saturates when a drop in downstream pressure can no longer increase the velocity. Choking occurs when the back-pressure ratio reaches the critical value characteristic of the valve. The block does not capture supersonic flow.

## Control Temperature

The temperature reading at the inlet is the control signal for the valve. The more the temperature reading rises over the activation temperature, the more the opening area diverges from maximally closed when **Valve operation** is **Opens above activation temperature**, or from fully open when **Valve operation** is **Closes above activation temperature**.

The difference between the sensor temperature reading and the activation temperature is the temperature overshoot. The block normalizes this variable against the temperature regulation range of the valve. The fraction of valve opening is

$$\hat{T} = \frac{T_S - T_{Act}}{\Delta T},$$

where  $T_S$  is the inlet sensor temperature reading and  $T_{Act}$  is the value of the **Activation temperature** parameter.

The difference,  $\Delta T$ , is the value of the **Temperature regulation range** parameter.

### Numerical Smoothing

When the **Smoothing factor** parameter is nonzero, the block applies numerical smoothing to the fraction of valve opening,  $\widehat{T}$ . Enabling smoothing helps maintain numerical robustness in your simulation.

For more information, see “Numerical Smoothing”.

### Sensor Dynamics

To emulate a real temperature sensor, which can only register a shift in temperature gradually, the block adds a first-order time lag to the temperature reading,  $T_S$ . The lag gives the sensor a transient response to variations in temperature. This expression for  $T_S$  is

$$\frac{d}{dt}T_S = \frac{T_{In} - T_S}{\tau},$$

where  $T_{In}$  is the actual inlet temperature at the current time step of the simulation and  $\tau$  is the value of the **Sensor time constant** parameter. The smaller this parameter is, the faster the sensor responds.

### Valve Parameterizations

The block behavior depends on the **Valve parametrization** parameter:

- **Cv flow coefficient** — The flow coefficient  $C_v$  determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization. The flow coefficient measures the ease with which a gas can flow when driven by a certain pressure differential.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization. The sonic conductance measures the ease with which a gas can flow when *choked*, which is a condition in which the flow velocity is at the local speed of sound. Choking occurs when the ratio between downstream and upstream pressures reaches a critical value known as the *critical pressure ratio*.
- **Orifice area** — The size of the flow restriction determines the block parametrization.

The block scales the specified flow capacity by the fraction of valve opening. As the fraction of valve opening rises from 0 to 1, the measure of flow capacity scales from its specified minimum to its specified maximum.

### Momentum Balance

The block equations depend on the **Orifice parametrization** parameter. When you set **Orifice parametrization** to **Cv flow coefficient** parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_v N_6 Y \sqrt{(p_{in} - p_{out}) \rho_{in}},$$

where:

- $C_v$  is the flow coefficient.
- $N_6$  is a constant equal to 27.3 for mass flow rate in kg/hr, pressure in bar, and density in kg/m<sup>3</sup>.

- $Y$  is the expansion factor.
- $p_{in}$  is the inlet pressure.
- $p_{out}$  is the outlet pressure.
- $\rho_{in}$  is the inlet density.

The expansion factor is

$$Y = 1 - \frac{p_{in} - p_{out}}{3p_{in}F_{\gamma}x_T},$$

where:

- $F_{\gamma}$  is the ratio of the isentropic exponent to 1.4.
- $x_T$  is the value of the **xT pressure differential ratio factor at choked flow** parameter.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ ,

$$\dot{m} = C_v N_6 Y_{lam} \sqrt{\frac{\rho_{avg}}{\rho_{avg}(1 - B_{lam})}} (p_{in} - p_{out}),$$

where:

$$Y_{lam} = 1 - \frac{1 - B_{lam}}{3F_{\gamma}x_T}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $1 - F_{\gamma}x_T$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = \frac{2}{3} C_v N_6 \sqrt{F_{\gamma} x_T p_{in} \rho_{in}}.$$

When you set **Orifice parametrization** to Kv flow coefficient parameterization, the block uses these same equations, but replaces  $C_v$  with  $K_v$  by using the relation  $K_v = 0.865C_v$ . For more information on the mass flow equations when the **Orifice parametrization** parameter is Kv flow coefficient parameterization or Cv flow coefficient parameterization, see [2][3].

When you set **Orifice parametrization** to Sonic conductance parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C \rho_{ref} p_{in} \sqrt{\frac{T_{ref}}{T_{in}}} \left[ 1 - \left( \frac{\frac{p_{out}}{p_{in}} - B_{crit}}{1 - B_{crit}} \right)^2 \right]^m,$$

where:

- $C$  is the sonic conductance.
- $B_{crit}$  is the critical pressure ratio.
- $m$  is the value of the **Subsonic index** parameter.
- $T_{ref}$  is the value of the **ISO reference temperature** parameter.

- $\rho_{ref}$  is the value of the **ISO reference density** parameter.
- $T_{in}$  is the inlet temperature.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter  $B_{lam}$ .

$$\dot{m} = C\rho_{ref}\sqrt{\frac{T_{ref}}{T_{avg}}}\left[1 - \left(\frac{B_{lam} - B_{crit}}{1 - B_{crit}}\right)^2\right]^m \left(\frac{p_{in} - p_{out}}{1 - B_{lam}}\right).$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below the critical pressure ratio,  $B_{crit}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C\rho_{ref}p_{in}\sqrt{\frac{T_{ref}}{T_{in}}}.$$

For more information on the mass flow equations when the **Orifice parametrization** parameter is Sonic conductance parameterization, see [1].

When you set **Orifice parametrization** to Orifice area parameterization, the mass flow rate,  $\dot{m}$ , is

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{in} \rho_{in} \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}} \frac{1 - \left(\frac{p_{out}}{p_{in}}\right)^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 \left(\frac{p_{out}}{p_{in}}\right)^{\frac{2}{\gamma}}}}$$

where:

- $S_r$  is the orifice or valve area.
- $S$  is the value of the **Cross-sectional area at ports A and B** parameter.
- $C_d$  is the value of the **Discharge coefficient** parameter.
- $\gamma$  is the isentropic exponent.

The block smoothly transitions to a linearized form of the equation when the pressure ratio,  $p_{out}/p_{in}$ , rises above the value of the **Laminar flow pressure ratio** parameter,  $B_{lam}$ .

$$\dot{m} = C_d S_r \sqrt{\frac{2\gamma}{\gamma-1} p_{avg}^{\frac{2-\gamma}{\gamma}} \rho_{avg} B_{lam}^{\frac{2}{\gamma}} \frac{1 - B_{lam}^{\frac{\gamma}{\gamma}}}{1 - \left(\frac{S_R}{S}\right)^2 B_{lam}^{\frac{2}{\gamma}}} \left(\frac{p_{in}^{\frac{\gamma-1}{\gamma}} - p_{out}^{\frac{\gamma-1}{\gamma}}}{1 - B_{lam}^{\frac{\gamma}{\gamma}}}\right)}.$$

When the pressure ratio,  $p_{out}/p_{in}$ , falls below  $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ , the orifice becomes choked and the block switches to the equation

$$\dot{m} = C_d S_R \sqrt{\frac{2\gamma}{\gamma+1} p_{in} \rho_{in} \frac{1}{\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}} - \left(\frac{S_R}{S}\right)^2}}.$$



For more information on the mass flow equations when the **Orifice parametrization** parameter is Orifice area parameterization, see [4].

### Mass Balance

The block assumes the volume and mass of fluid inside the valve is very small and ignores these values. As a result, no amount of fluid can accumulate in the valve. By the principle of conservation of mass, the mass flow rate into the valve through one port equals that out of the valve through the other port

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}$  is defined as the mass flow rate into the valve through the port indicated by the **A** or **B** subscript.

### Energy Balance

The resistive element of the block is an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. Energy can flow only by advection, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows is always equal to zero

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is the energy flow rate into the valve through ports **A** or **B**.

### Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

### Assumptions and Limitations

- The **Sonic conductance** setting of the **Valve parameterization** parameter is for pneumatic applications. If you use this setting for gases other than air, you may need to scale the sonic conductance by the square root of the specific gravity.
- The equation for the **Orifice area** parameterization is less accurate for gases that are far from ideal.
- This block does not model supersonic flow.

## Ports

### Conserving

#### A — Valve entrance

gas

Gas conserving port associated with the opening through which the flow enters or exits the valve. The direction of flow depends on the pressure differential established across the valve. The block allows both forward and backward directions.

### **B – Valve entrance**

gas

Opening through which the working fluid can enter or exit the valve. The direction of flow depends on the pressure differential established across the valve. The block allows both forward and backward directions.

## **Parameters**

### **Valve operation – Sign of change in opening area**

Opens above activation temperature (default) | Closes above activation temperature

Sign of the change in opening area that is induced by warming. The opening area can expand with a rise in temperature or it can contract. The change begins at an activation temperature and continues with warming conditions throughout the temperature regulation range of the valve.

The default setting corresponds to a normally closed valve that opens with rising temperature. The alternative setting corresponds to a normally open valve that closes with the same.

### **Activation temperature – Temperature at which opening mechanism is triggered**

330 K (default) | scalar

Temperature at which the opening mechanism is triggered. Warming above this temperature will either open or close the valve, depending on the setting of the **Valve operation** parameter. The opening area remains variable throughout the temperature regulation range of the valve.

### **Temperature regulation range – Span of temperature interval over which opening area is variable**

8 K (default) | positive scalar

Span of the temperature interval over which the valve opening area varies with temperature. The interval begins at the activation temperature of the valve. It ends at the sum of the same with the regulation range specified here.

### **Sensor time constant – Time for temperature change to register at inlet sensor**

1.5 s (default) | positive scalar in units of time

Characteristic time for a temperature change to register at the inlet sensor. This parameter determines the delay between the onset of a change and a stable measurement of the same, taken as the sensor nears its new steady state. A value of 0 means that the sensor responds instantaneously to a temperature change.

### **Valve parameterization – Parameterization used to specify flow characteristics of orifice**

Cv flow coefficient (default) | Kv flow coefficient | Sonic conductance | Orifice area

Method to calculate the mass flow rate.

- Cv flow coefficient – The flow coefficient  $C_v$  determines the block parameterization.

- **Kv flow coefficient** — The flow coefficient  $K_v$ , where  $K_v = 0.865C_v$ , determines the block parameterization.
- **Sonic conductance** — The sonic conductance of the resistive element at steady state determines the block parameterization.
- **Orifice area** — The size of the flow restriction determines the block parameterization.

**Maximum Cv flow coefficient — Cv coefficient that corresponds to maximally open component**

4 (default) | positive scalar

Value of the  $C_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient.

**xT pressure differential ratio factor at choked flow — Ratio of pressure differentials**

0.7 (default) | positive scalar

Ratio between the inlet pressure,  $p_{in}$ , and the outlet pressure,  $p_{out}$ , defined as  $(p_{in} - p_{out})/p_{in}$  where choking first occurs. If you do not have this value, look it up in table 2 in ISA-75.01.01 [3]. Otherwise, the default value of 0.7 is reasonable for many valves.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Cv flow coefficient or Kv flow coefficient.

**Maximum Kv flow coefficient — Kv coefficient that corresponds to maximally open component**

3.6 (default) | positive scalar

Maximum value of the  $K_v$  flow coefficient when the restriction area available for flow is at a maximum. This parameter measures the ease with which the gas traverses the resistive element when driven by a pressure differential.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Kv flow coefficient.

**Maximum sonic conductance — Sonic conductance corresponding to maximally open component**

12 l/(bar\*s) (default) | positive scalar

Value of the sonic conductance when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Sonic conductance.

**Critical pressure ratio — Ratio of downstream and upstream pressures at which the flow first chokes**

0.3 (default) | positive scalar

Pressure ratio at which flow first begins to choke and the flow velocity reaches its maximum, given by the local speed of sound. The pressure ratio is the outlet pressure divided by inlet pressure.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**Subsonic index – Exponent used to characterize mass flow in subsonic flow regime**

0.5 (default) | positive scalar

Empirical value used to more accurately calculate the mass flow rate in the subsonic flow regime.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**ISO reference temperature – ISO 8778 reference temperature**

293.15 K (default) | scalar

Temperature at standard reference atmosphere, defined as 293.15 K in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**ISO reference density – ISO 8778 reference density**

1.185 kg/m<sup>3</sup> (default) | positive scalar

Density at standard reference atmosphere, defined as 1.185 kg/m<sup>3</sup> in ISO 8778.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Sonic conductance`.

**Maximum orifice area – Flow area corresponding to maximally open component**

1e-4 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of the orifice opening when the cross-sectional area available for flow is at a maximum.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar in the range of [0,1]

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set **Valve parameterization** to `Orifice area`.

**Leakage flow fraction – Ratio of flow rates**

1e-6 (default) | positive scalar

Ratio of the flow rate of the orifice when it is closed to when it is open.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this parameter to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Laminar flow pressure ratio – Pressure ratio at which flow transitions between laminar and turbulent regimes**

0.999 (default) | positive scalar

Pressure ratio at which flow transitions between laminar and turbulent flow regimes. The pressure ratio is the outlet pressure divided by inlet pressure. Typical values range from 0.995 to 0.999.

**Cross-sectional area at ports A and B – Flow area at gas ports**0.01 m<sup>2</sup> (default) | positive scalar

Area normal to the flow path at each port. The ports are equal in size. The value of this parameter should match the inlet area of the components to which the resistive element connects.

## Version History

**Introduced in R2018b****Model gas systems using improved flow computations**

In previous versions, the blocks in the gas library used a conversion factor to implement different orifice parameterizations in terms of sonic conductance. You can use the **Valve parameterization** parameter to specify the parameterization.

The new parameterizations also include new parameters:

- **xT pressure differential ratio factor at choked flow**
- **Discharge coefficient**
- **Leakage flow fraction.** This parameter replaces the **Cv coefficient (USCS) at leakage flow**, **Kv coefficient (SI) at leakage flow**, **Sonic conductance at leakage flow**, and **Restriction area at leakage flow** parameters.

To improve clarity:

- The **Opening parameterization** parameter has been renamed to **Opening characteristic**.
- The **Reference temperature** and **Reference density** parameters have been renamed to **ISO reference temperature** and **ISO reference density**, respectively.
- The **Cv coefficient (USCS) at maximum flow** and **Kv coefficient (USCS) at maximum flow** parameters have been renamed to **Maximum Cv coefficient** and **Maximum Kv coefficient**, respectively.
- The **Sonic conductance at maximum flow** parameter has been renamed to **Maximum sonic conductance**.

## References

- [1] ISO 6358-3. "Pneumatic fluid power – Determination of flow-rate characteristics of components using compressible fluids – Part 3: Method for calculating steady-state flow rate characteristics of systems". 2014.
- [2] IEC 60534-2-3. "Industrial-process control valves – Part 2-3: Flow capacity – Test procedures". 2015.
- [3] ANSI/ISA-75.01.01. "Industrial-Process Control Valves – Part 2-1: Flow capacity – Sizing equations for fluid flow underinstalled conditions". 2012.
- [4] P. Beater. *Pneumatic Drives*. Springer-Verlag Berlin Heidelberg. 2007.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Orifice (G) | Poppet Valve (G) | Gate Valve (G)

# Temperature Control Valve (TL)

Flow control valve with temperature-based actuation

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices / Flow Control Valves



## Description

The Temperature Control Valve (TL) block models an orifice with a thermostat as a flow control mechanism. The thermostat contains a temperature sensor and a black-box opening mechanism—one whose geometry and mechanics matter less than its effects. The sensor responds with a slight delay, captured by a first-order time lag, to variations in temperature.

When the sensor reads a temperature in excess of a preset activation value, the opening mechanism is actuated. The valve begins to open or close, depending on the chosen operation mode—the first case corresponding to a normally closed valve and the second to a normally open valve. The change in opening area continues up to the limit of the valve's temperature regulation range, beyond which the opening area is a constant.

A smoothing function allows the valve opening area to change smoothly between the fully closed and fully open positions. The smoothing function does this by removing the abrupt opening area changes at the zero and maximum ball positions.

## Mass Balance

The mass conservation equation in the valve is

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate into the valve through port **A**.
- $\dot{m}_B$  is the mass flow rate into the valve through port **B**.

## Momentum Balance

The momentum conservation equation in the valve is

$$p_A - p_B = \frac{\dot{m}\sqrt{\dot{m}^2 + \dot{m}_{cr}^2}}{2\rho_{Avg}C_d^2S^2} \left[ 1 - \left( \frac{S_R}{S} \right)^2 \right] PR_{Loss},$$

where:

- $p_A$  and  $p_B$  are the pressures at port A and port B.
- $\dot{m}$  is the mass flow rate.

- $\dot{m}_{cr}$  is the critical mass flow rate:

$$\dot{m}_{cr} = Re_{cr} \mu_{Avg} \sqrt{\frac{\pi}{4} S_R}.$$

- $\rho_{Avg}$  is the average liquid density.
- $C_d$  is the discharge coefficient.
- $S$  is the valve inlet area.
- $PR_{Loss}$  is the pressure ratio:

$$PR_{Loss} = \frac{\sqrt{1 - (S_R/S)^2 (1 - C_d^2)} - C_d(S_R/S)}{\sqrt{1 - (S_R/S)^2 (1 - C_d^2)} + C_d(S_R/S)}.$$

### Energy Balance

The energy conservation equation in the valve is

$$\phi_A + \phi_B = 0,$$

where:

- $\phi_A$  is the energy flow rate into the valve through port A.
- $\phi_B$  is the energy flow rate into the valve through port B.

### Valve Opening Area

The valve opening area calculation is based on the linear expression

$$S_{Linear} = \left( \frac{S_{End} - S_{Start}}{T_{Range}} \right) (T_{Sensor} - T_{Activation}) + S_{Start},$$

where:

- $S_{Linear}$  is the linear valve opening area.
- $S_{Start}$  is the valve opening area at the beginning of the temperature actuation range. This area depends on the **Valve operation** parameter setting:

$$S_{Start} = \begin{cases} S_{Leak}, & \text{Valve opens above activation temperature} \\ S_{Max}, & \text{Valve closes above activation temperature} \end{cases}$$

- $S_{End}$  is the valve opening area at the end of the temperature actuation range. This area depends on the **Valve operation** parameter setting:

$$S_{End} = \begin{cases} S_{Max}, & \text{Valve opens above activation temperature} \\ S_{Leak}, & \text{Valve closes above activation temperature} \end{cases}$$

- $S_{Max}$  is the valve opening area in the fully open position.
- $S_{Leak}$  is the valve opening area in the fully closed position. Only leakage flow remains in this position.
- $T_{Range}$  is the temperature regulation range.
- $T_{Activation}$  is the minimum temperature required to operate the valve.



- $T_{\text{Sensor}}$  is the measured valve temperature.

The valve model accounts for a first-order lag in the measured valve temperature through the differential equation:

$$\frac{d}{dt}(T_{\text{Sensor}}) = \frac{T_{\text{Avg}} - T_{\text{Sensor}}}{\tau},$$

where:

- $T_{\text{Avg}}$  is the arithmetic average of the valve port temperatures,

$$T_{\text{Avg}} = \frac{T_A + T_B}{2},$$

where  $T_A$  and  $T_B$  are the temperatures at ports A and B.

- $\tau$  is the **Sensor time constant** value specified in the block dialog box.

When the valve is in a near-open or near-closed position you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the valve area between  $S_{\text{Leak}}$  and  $S_{\text{Max}}$ . For more information, see “Numerical Smoothing”.

## Ports

### Conserving

#### A — Liquid port

thermal liquid

Thermal liquid conserving port representing valve inlet A.

#### B — Liquid port

thermal liquid

Thermal liquid conserving port representing valve inlet B.

## Parameters

### Valve operation — Sign of the change in opening area induced by warming

Opens above activation temperature (default) | Closes above activation temperature

Sign of the change in opening area induced by warming. The opening area can expand with a rise in temperature or it can contract. The change begins at an activation temperature and continues with warming conditions throughout the temperature regulation range of the valve.

The default setting corresponds to a normally closed valve that opens with rising temperature; the alternative setting corresponds to a normally open valve that closes with the same.

### Activation temperature — Temperature at which the opening mechanism triggers

330 K (default) | positive scalar

Temperature at which the opening mechanism triggers. Warming above this temperature will either open or close the valve, depending on the setting of the **Valve operation** parameter. The opening area remains variable throughout the temperature regulation range of the valve.

**Temperature regulation range — Valve temperature range**

8 K (default) | positive scalar

Temperature interval over which the valve opening area varies. The interval begins at the value of the **Activation temperature** parameter.

**Sensor time constant — Time for a temperature change to register at the inlet sensor**

1.5 s (default) | nonnegative scalar

Characteristic time for a temperature change to register at the inlet sensor. This parameter determines the delay between the onset of a change and a stable measurement of the change. A value of 0 means that the sensor responds instantaneously to a temperature change.

**Maximum opening area — Opening area in the fully open position due to sealing imperfections**

1e-4 m<sup>2</sup> (default) | positive scalar

Opening area of the valve in the fully open position, when the valve is at the upper limit of the pressure regulation range. The block uses this parameter to scale the valve opening throughout the pressure regulation range.

**Leakage area — Opening area in the maximally closed position due to sealing imperfections**

1e-12 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is saturated to the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions.

**Cross-sectional area at ports A and B — Orifice area at conserving ports**

0.01 m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Discharge coefficient — Discharge coefficient**

0.7 (default) | positive scalar

Correction factor accounting for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

12 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the valve.

## **Version History**

**Introduced in R2016a**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Gate Valve (TL) | Poppet Valve (TL)

# Thermal Liquid Properties (TL)

Preset fluid properties for the simulation of a thermal liquid network

**Library:** Simscape / Fluids / Thermal Liquid / Utilities



## Description

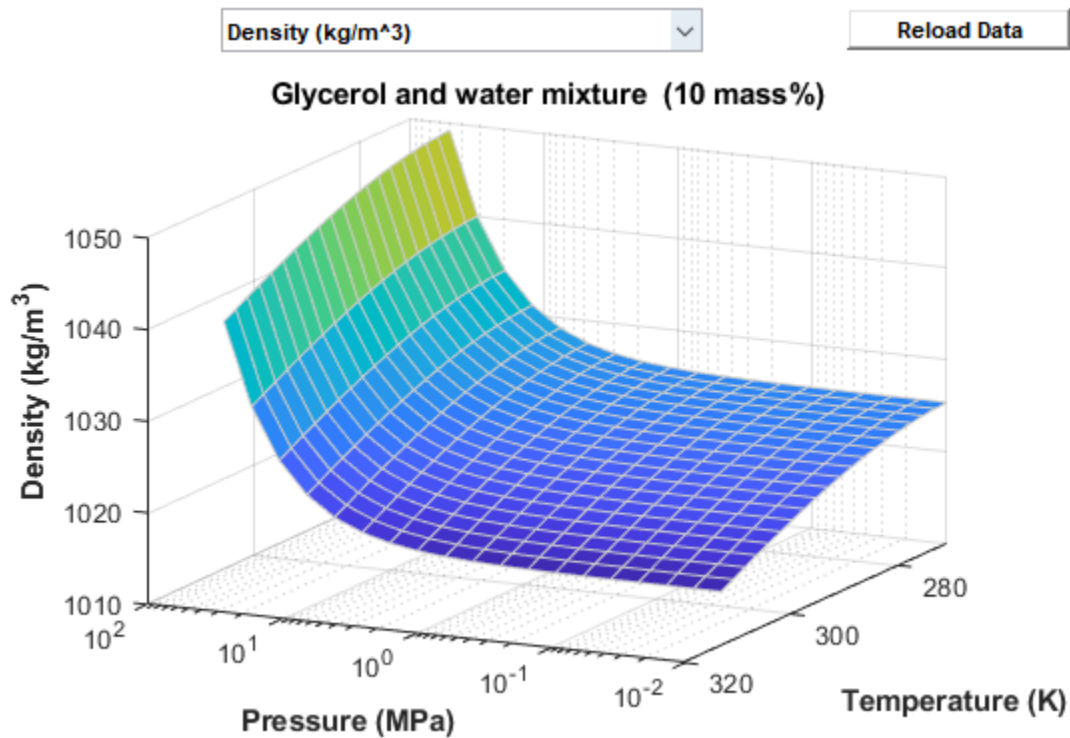
The Thermal Liquid Properties (TL) block set predefined fluid properties to a thermal liquid network. The available fluids include pure water, aqueous mixtures, diesel, aviation fuel Jet A, and SAE 5W-30. You can use this block as a preset alternative to the Thermal Liquid Settings (TL) block. If your network does not have a connected liquid properties block, or the liquid defaults will apply. See “Specify Fluid Properties” for more details

The preset fluid properties are defined in tabular form as functions of temperature and pressure. During simulation, the network properties are set by linear interpolation between data points. Tabular data for aqueous mixtures is provided for concentration by mass or volume.

All the fluid properties commonly specified in the Thermal Liquid Settings (TL) block are defined in the block. These properties include density, the bulk modulus and thermal expansion coefficient, the specific internal energy and specific heat, as well as the kinematic viscosity and thermal conductivity. The properties are valid over a limited region of temperatures and pressures specific to the fluid selected and dependent, in the cases of mixtures, on the concentration specified. Simulation is allowed within this validity region only.

## Data Visualization

You can visualize the fluid properties defined in the block and the pressure and temperature regions of validity. To open the visualization utility, right-click the block and select **Fluids > Plot Fluid Properties**. The plot updates automatically upon selection of a fluid property from the drop-down list. Use the **Reload Data** button to regenerate the plot whenever the fluid selection or fluid parameters change.

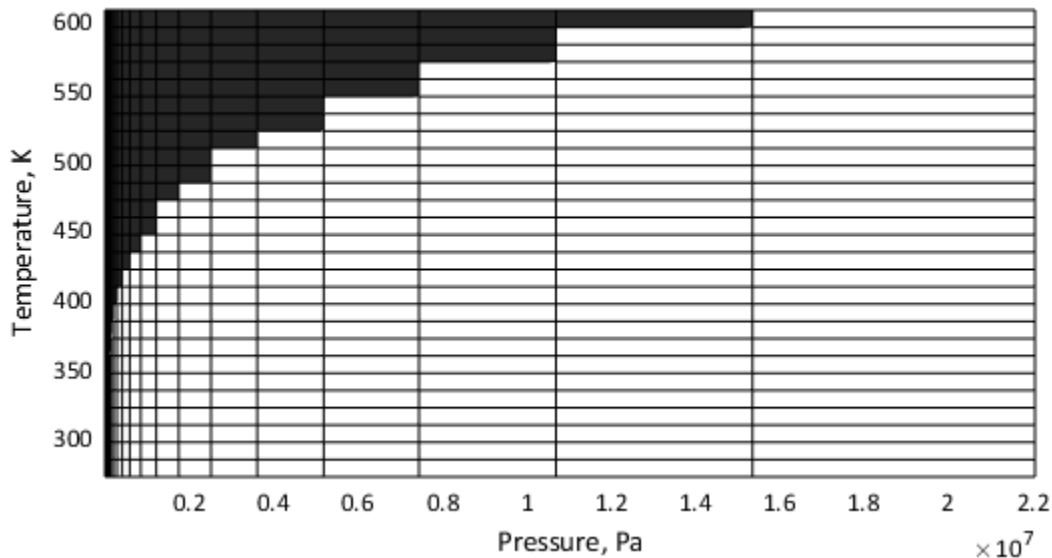


### Visualization of density data for a 10% glycerol aqueous mixture

#### Validity Regions

The validity regions are defined in the block as matrices of zeros and ones. Each row corresponds to a tabulated temperature and each column to a tabulated pressure. A zero denotes an invalid breakpoint and a one a valid breakpoint. These validity matrices are internal to the block and cannot be modified; they can only be checked (using the data visualization utility of the block).

In most cases, the validity matrices are extracted directly from the tabulated data. The glycol and glycerol mixtures pressure boundaries are not available from the data, and are obtained explicitly from block parameters. The figure below shows an example of the validity region for water. The shaded squares indicate temperature and pressure regions outside of the validity region.



### Water

The properties of water are valid at temperatures above the triple-point value (273.160 K) up to the critical-point value (647.096 K). They are valid at pressures above the greater of the triple-point value (611.657 Pa) on one hand and the temperature-dependent saturation value on the other, up to the critical-point value (22.064 MPa). Pressures below the saturation point for a given temperature row are assigned a value of 0 in the validity matrix.

### Seawater (MIT model)

The properties of seawater are valid at temperatures above 0°C up to 120°C (273.15 K to 393.15 K); they are valid at pressures above the saturation point up to a maximum value of 12 MPa. Pressures below the saturation point for a given temperature row (and at the specified concentration level) are assigned a value of 0 in the validity matrix. Mixture concentrations can range in value from 0 to 0.12 on a mass fraction basis.

### Ethylene glycol and water mixture

The properties of an aqueous ethylene glycol mixture are valid over a temperature domain determined from the mixture concentration; they are valid at pressures within the minimum and maximum bounds specified in the block dialog box (extended horizontally to span the width of the temperature rows).

The lower temperature bound is always the lesser of the minimum temperature extracted from the available data and the freezing point of the mixture (the mixture must be in the liquid state). The upper temperature bound is always the maximum temperature extracted from the data. Mixture concentrations can range in value from 0 to 0.6 if a mass-fraction basis is used, or from 0 to 1 if a volume fraction basis is used.

### Propylene glycol and water mixture

The properties of an aqueous propylene glycol mixture are valid over the temperature and pressure ranges described for the case of Ethylene glycol and water mixture. Mixture concentrations can range in value from 0 to 0.6 if a mass-fraction basis is used, or from 0.1 to 0.6 if a volume fraction basis is used.

**Glycerol and water mixture**

The properties of an aqueous glycerol mixture are valid over the temperature and pressure ranges as described for the case of Ethylene glycol and water mixture. Mixture concentrations can range in value from 0 to 0.6 on a mass-fraction basis. The properties are all extended to 100 degC as:

- Density—quadratic fit
- Alpha (density thermal derivative)—linear fit
- Specific heat—linear fit
- Specific internal energy—linear fit
- Kinematic viscosity—exponential fit based on the upper half of the original temperature range
- Dynamic viscosity—exponential fit based on the upper half of the original temperature range
- Prandtl number—exponential fit based on the upper half of the original temperature range

**Aviation fuel Jet-A**

The properties of Jet A fuel are valid at temperatures above -50.93°C up to 372.46°C (222.22 K to 645.61 K); they are valid at pressures above the saturation point up to a maximum value of 2.41 MPa. Pressures below the saturation point for a given temperature row are assigned a value of 0 in the validity matrix.

**Diesel fuel**

The properties of diesel fuel are valid at temperatures above -34.95°C up to 417.82°C (238.20 K to 690.97 K); they are valid at pressures above the saturation point up to a maximum value of 2.29 MPa. Pressures below the saturation point for a given temperature row are assigned a value of 0 in the validity matrix.

**SAE 5W-30**

The properties of SAE 5W-30 fuel derive from data covering different temperature and pressure ranges for each property but all extended by extrapolation to (-38, 200) C and (0.01, 100) MPa.

**Calculated Properties**

The density and thermal expansion coefficients of the aqueous mixtures of glycol and glycerol compounds are obtained from the block parameters. The fluid density, with respect to pressure and temperature, is calculated as:

$$\rho(T, p) = \rho(T) \exp\left(\frac{p - p_R}{\beta}\right),$$

where:

- $T$  is the network temperature.
- $p$  is the network pressure.
- $\rho$  is the fluid density.
- $p_R$  is the reference pressure associated with the fluid property tables.
- $\beta$  is the isothermal bulk modulus.

where the change in fluid density is evaluated as:

$$\left(\frac{\partial \rho(T, p)}{\partial T}\right)_p = \left(\frac{\partial \rho(T)}{\partial T}\right)_T \exp\left(\frac{p - p_R}{\beta}\right).$$

The thermal expansion coefficient is calculated as:

$$\alpha(T, p) = -\frac{1}{\rho(T, p)} \left(\frac{\partial \rho(T)}{\partial T}\right)_T \exp\left(\frac{p - p_R}{\beta}\right).$$

## Ports

### Conserving

#### R – Thermal liquid network for which to define the working fluid

thermal liquid

Node identifying the thermal liquid network for which to define the necessary fluid properties. The fluid selected in this block applies to the entire network. No other Thermal Liquid Properties (TL) or Thermal Liquid Settings (TL) block may be connected to the same network.

## Parameters

### Thermal liquid fluid list – Available working fluids

Water (default) | Seawater (MIT model) | Ethylene glycol and water mixture | Propylene glycol and water mixture | Glycerol and water mixture | Diesel Fuel | Aviation fuel Jet-A | SAE 5W-30

Sets the fluid properties of your liquid network. The available fluids include pure water, aqueous mixtures, motor oils, and fuels.

### Dissolved salt mass fraction (salinity) – Mass of salt divided by the total mass of the saline mixture

3.5e-3 (default) | positive unitless scalar valued between 0 and 1

Ratio of the mass of salt present in the saline mixture to the total mass of that mixture.

### Dependencies

This parameter is active only when Seawater (MIT model) is selected as the working fluid.

### Concentration type – Quantity in terms of which the mixture concentration is defined

Volume fraction (default) | Mass fraction

Quantity in terms of which to specify the concentration of ethylene glycol in its aqueous mixture. This parameter is active only when either Ethylene glycol and water mixture or Propylene glycol and water mixture is selected as the working fluid.

### Ethylene glycol volume fraction – Volume of ethylene glycol divided by that of the aqueous mixture

0.1 (default) | positive unitless scalar valued between 0 and 1

Volume of ethylene glycol present in the aqueous mixture divided by the total volume of that mixture.



**Dependencies**

This parameter is active when Ethylene glycol and water mixture is selected as the working fluid and Volume fraction is selected as the concentration type.

**Ethylene glycol mass fraction — Mass of ethylene glycol divided by that of the aqueous mixture**

0.1 (default) | positive unitless scalar valued between 0 and 1

Mass of ethylene glycol present in the aqueous mixture divided by the total mass of that mixture.

**Dependencies**

This parameter is active when Ethylene glycol and water mixture is selected as the working fluid and Mass fraction is selected as the concentration type.

**Propylene glycol volume fraction — Mass of propylene glycol divided by that of the aqueous mixture**

0.1 (default) | positive unitless scalar valued between 0 and 1

Volume of propylene glycol present in the aqueous mixture divided by the total volume of that mixture.

**Dependencies**

This parameter is active when Propylene glycol and water mixture is selected as the working fluid and Volume fraction is selected as the concentration type.

**Propylene glycol mass fraction — Mass of propylene glycol divided by that of the aqueous mixture**

0.1 (default) | positive unitless scalar valued between 0 and 1

Mass of propylene glycol present in the aqueous mixture divided by the total mass of that mixture.

**Dependencies**

This parameter is active when Propylene glycol and water mixture is selected as the working fluid and Mass fraction is selected as the concentration type.

**Isothermal bulk modulus — Measure of fluid compressibility specified at constant temperature**

2.1791 GPa (default) | positive scalar with units of pressure

Bulk modulus of the aqueous mixture at constant temperature. The bulk modulus measures the change in pressure required to produce a fractional change in fluid volume.

**Dependencies**

This parameter is active when either Ethylene glycol and water mixture, Propylene glycol and water mixture, or Glycerol and water mixture is selected as the working fluid.

**Minimum valid pressure — Lower bound of the allowed pressure range for the thermal liquid network**

0.01 MPa (default) | positive scalar with units of pressure

Lower bound of the pressure range allowed in the thermal liquid network connected to this block.

**Dependencies**

This parameter is active when either Ethylene glycol and water mixture, Propylene glycol and water mixture, or Glycerol and water mixture is selected as the working fluid.

**Maximum valid pressure — Upper bound of the allowed pressure range for the thermal liquid network**

50 MPa (default) | positive scalar with units of pressure

Upper bound of the pressure range allowed in the thermal liquid network connected to this block.

**Dependencies**

This parameter is active when either Ethylene glycol and water mixture, Propylene glycol and water mixture, or Glycerol and water mixture is selected as the working fluid.

**Atmospheric pressure — Absolute pressure in the environment of the thermal liquid network**

0.101325 MPa (default) | positive scalar with units of pressure

Absolute pressure of the external environment in which the thermal liquid network is assumed to run. The default value is the standard atmospheric pressure measured at sea level on Earth.

## Version History

Introduced in R2018a

## References

- [1] Massachusetts Institute of Technology (MIT), *Thermophysical properties of seawater database*. <http://web.mit.edu/seawater>.
- [2] K.G. Nayar, M.H. Sharqawy, L.D. Banchik, J.H. Lienhard V, Thermophysical properties of seawater: A review and new correlations that include pressure dependence, *Desalination*, Vol. 390, pp. 1-24, 2016.
- [3] M.H. Sharqawy, J.H. Lienhard V, S.M. Zubair, Thermophysical properties of seawater: A review of existing correlations and data, *Desalination and Water Treatment*, Vol. 16, pp. 354-380.

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Thermal Liquid Settings (TL)

## Thermostatic Expansion Valve (2P)

Flow control valve that maintains evaporator superheat

**Library:** Simscape / Fluids / Two-Phase Fluid / Valves & Orifices / Flow Control Valves



### Description

The Thermostatic Expansion Valve (2P) block models a valve with a pressure drop that maintains an evaporator superheat in a two-phase fluid network. You typically place this valve between a condenser and an evaporator in a refrigeration system to maintain a specific temperature differential by moderating the flow into the evaporator.

The valve behavior depends on the *superheat*, which is the difference in temperature between the vapor at the evaporator outlet and the fluid evaporating temperature. The valve opens if the superheat increases to let more flow through, and the valve closes if the superheat decreases to let less flow through. When the superheat drops to or below the value of the **Static (minimum) evaporator superheat** parameter, then the valve is fully closed. The closed valve reduces the flow through the evaporator, which reduces the heat transfer and increases the outlet temperature. When you use the **MOP limit** parameter to enable a maximum pressure or temperature limit, the valve closes when the temperature or pressure exceeds the limit.

The bulb sensor at port **S** measures the evaporator outlet temperature. If you set the **Pressure equalization** parameter to `External pressure equalization`, the block uses data from the evaporator at port **E** for internal pressure equalization. Otherwise, the block uses the pressure at port **B** for internal pressure equalization. The block balances the bulb pressure, which acts to open the valve, with the valve equalization pressure, which acts to close the valve.

### Analytical Parameterization

When you set **Valve parameterization** to `Nominal capacity, superheat, and operating conditions`, the block uses an analytical model. In this setting, the block fits the analytical model to the performance data so that when the refrigeration system operates at the specified nominal evaporating temperature, condensing temperature, and condenser subcooling, the block meters enough flow into the evaporator to maintain the evaporator superheat while the block transfers heat at the evaporator capacity. Subcooling is the difference in temperature between the condenser outlet and the condensing temperature.

For this parameterization, the block assumes a straight-charged bulb and assumes that the sensing bulb contains the same fluid as the refrigerant. To model a cross-charged bulb, set **Valve parameterization** to `Tabulated data - quadrant diagram`.

### Opening Area

The valve operates to control the mass flow rate between a condenser and an evaporator by regulating the effective opening area,  $S_{eff}$ . The mass flow rate is

$$\dot{m} = S_{eff} \sqrt{\frac{2}{v_{in}} \frac{\Delta p}{(\Delta p^2 - \Delta p_{lam}^2)^{0.25}}}$$

where:

- $v_{in}$  is the inlet specific volume, or the fluid volume per unit mass.
- $\Delta p$  is the pressure differential over the valve,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure threshold for transitional flow. Below this value, the flow is laminar

$$\Delta p_{lam} = \frac{p_A + p_B}{2} (1 - B_{lam}),$$

where  $B_{lam}$  is the value of the **Laminar flow pressure ratio** parameter.

The effective valve area depends on the pressure difference between the measured pressure,  $p_{bulb}$  and the equalization pressure,  $p_{eq}$

$$S_{eff} = \beta [(p_{bulb} - p_{eq}) - (p_{sat}(T_{evap} + \Delta T_{static}) - p_{sat}(T_{evap}))],$$

where:

- $\beta$  is a valve constant determined from the nominal operating conditions. See “Determining  $\beta$  from Nominal Conditions” on page 1-1871.
- $T_{evap}$  is the evaporating temperature.

When **Nominal pressure specification** is Pressure at specified saturation temperature,  $T_{evap}$  is the value of the **Nominal evaporating (saturation) temperature** parameter.

When **Nominal pressure specification** is Specified pressure,  $T_{evap}$  is the saturation temperature that corresponds to the value of the **Nominal evaporator outlet pressure** parameter.

- $\Delta T_{static}$  is the **Static (minimum) evaporator superheat** parameter.
- $p_{sat}(T_{evap})$  is the fluid saturation pressure as a function of  $T_{evap}$ . The block uses the `tablelookup` function to identify this value.
- $p_{sat}(T_{evap} + \Delta T_{static})$  is the saturation pressure as a function of  $T_{evap} + \Delta T_{static}$ . The block uses the `tablelookup` function to identify this value.
- $p_{bulb}$  is the fluid pressure of the bulb. The bulb pressure is the saturation pressure,  $p_{bulb} = p_{sat}(T_{bulb})$ , unless you set **MOP limit** to On - Specify maximum operating pressure and the pressure reaches the maximum pressure. See “Maximum Outlet Pressure Limit” on page 1-1872 for more information.  $T_{bulb}$  is the bulb fluid temperature.
- $p_{eq}$  depends on the valve pressure equalization setting:
  - When you set **Pressure equalization** to Internal pressure equalization,  $p_{eq}$  is the pressure at port **B**.
  - When you set **Pressure equalization** to External pressure equalization,  $p_{eq}$  is the pressure at port **E**.

The effective valve area has limits. The minimum effective valve area,  $S_{eff,min}$ , is

$$S_{eff,min} = f_{leak} S_{eff,nom}$$

where  $f_{leak}$  is the value of the **Closed valve leakage as a fraction of nominal flow** parameter. To see how the block calculates the nominal effective valve area,  $S_{eff,nom}$  and maximum effective valve area, see “Determining  $\beta$  from Nominal Conditions” on page 1-1871.

#### Determining $\beta$ from Nominal Conditions

$\beta$  represents the relationship between the nominal evaporator superheat and the nominal evaporator capacity, the rate of heat transfer between the two fluids in the evaporator:

$$\beta = \frac{S_{eff,nom}}{[p_{sat}(T_{evap} + \Delta T_{nom}) - p_{sat}(T_{evap})]}$$

where  $p_{sat}(T_{evap} + \Delta T_{nom})$  is the saturation pressure at the sum of the evaporator outlet temperature and the **Nominal (static + opening) evaporator superheat** parameter.

The block calculates the nominal effective valve area,  $S_{eff,nom}$ , as a function of the nominal condenser and evaporator thermodynamics. When **Capacity specification** is Evaporator heat transfer, the nominal effective valve area is

$$S_{eff,nom} = \frac{\left[ \frac{Q_{nom}}{c_{p,evap}\Delta T_{nom} + h_{evap} - h_{cond} + c_{p,cond}\Delta T_{sub}} \right]}{\sqrt{\frac{2}{v_{cond}}(p_{sat}(T_{cond}) - p_{sat}(T_{evap}))}}$$

When **Capacity specification** is Mass flow rate, the nominal effective valve area is

$$S_{eff,nom} = \frac{\dot{m}_{nom}}{\sqrt{\frac{2}{v_{cond}}(p_{sat}(T_{cond}) - p_{sat}(T_{evap}))}}$$

where:

- $T_{cond}$  is the condensing saturation temperature.

When **Nominal pressure specification** is Pressure at specified saturation temperature,  $T_{cond}$  is the value of the **Nominal condensing (saturation) temperature** parameter.

When **Nominal pressure specification** is Specified pressure,  $T_{cond}$  is the saturation temperature that corresponds to the value of the **Nominal condenser outlet pressure** parameter.

- $v_{cond}$  is the liquid specific volume at  $T_{cond}$ .
- $Q_{nom}$  is the **Nominal evaporator heat transfer** parameter.
- $c_{p,evap}$  is the vapor specific heat at  $T_{evap}$ .
- $h_{evap}$  is the vapor specific enthalpy at  $T_{evap}$ .
- $c_{p,cond}$  is the liquid specific heat at  $T_{cond}$ .
- $h_{cond}$  is the liquid specific enthalpy at  $T_{cond}$ .
- $\Delta T_{sub}$  is the **Nominal condenser subcooling** parameter.
- $\dot{m}_{nom}$  is the **Nominal mass flow rate** parameter.

When **Capacity specification** is Evaporator heat transfer, the block determines the maximum effective area of the valve in the same way as  $S_{eff,nom}$ , but uses the value of **Maximum evaporator**

**heat transfer** parameter instead of the **Nominal evaporator heat transfer** parameter. When **Capacity specification** is Mass flow rate, the block uses the value of the **Maximum mass flow rate** parameter instead of the **Nominal mass flow rate** parameter.

#### Maximum Outlet Pressure Limit

You can limit the maximum outlet pressure (MOP) in the evaporator by setting the **MOP limit** parameter to On - Specify maximum operating pressure or On - Specify maximum operating temperature. When you use one of these settings, the valve closes when the bulb temperature or pressure exceeds the temperature or pressure associated with maximum bulb pressure, and opens once the pressure reduces. If you set **MOP limit** to Off, or the measured pressure is below the limit,  $p_{bulb} = p_{sat}(T_{bulb})$ . Otherwise, when the measurement exceeds the limit, the bulb pressure remains at

$$p_{bulb} = \frac{p_{bulb,MOP}}{T_{bulb,MOP}} T_{bulb},$$

where:

- $p_{bulb,MOP}$  is a function of the **Maximum evaporator outlet pressure** parameter,  $p_{eq,MOP}$ , or the pressure specified by the **Maximum evaporating (saturation) temperature** parameter, and the nominal evaporator temperature:

$$p_{bulb,MOP} = p_{eq,MOP} + p_{sat}(T_{evap} + \Delta T_{static}) - p_{sat}(T_{evap}).$$

- $T_{bulb}$  is the bulb fluid temperature. This value is the temperature at port **S** if **Bulb temperature dynamics** is set to Off. The block applies a first-order delay to the bulb temperature if **Bulb temperature dynamics** is set to On.
- $T_{bulb,MOP}$  is the associated temperature at the pressure  $p_{bulb,MOP}$ .

#### Four-Quadrant Diagram

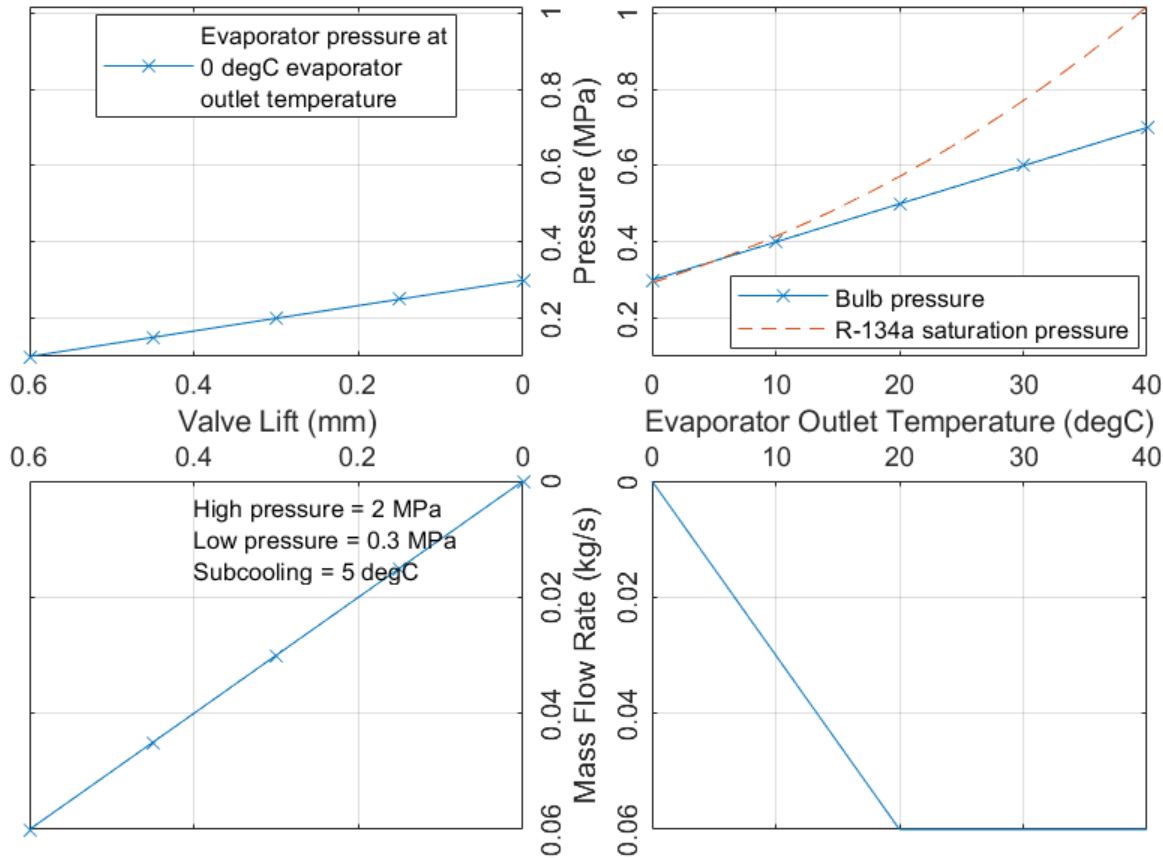
To visualize the four-quadrant diagram, right-click the block and select **Fluids > Plot 4-Quadrant Diagram**.

When **Valve parameterization** is Tabulated data - quadrant diagram, the block uses user-provided data to plot in all quadrants. See “Tabulated Data Parameterization” on page 1-1874.

When **Valve parameterization** is Nominal capacity, superheat, and operating conditions, the block calculates the data in all quadrants by using the analytical valve model, described in “Analytical Parameterization” on page 1-1869. Because the analytical model assumes a straight-charged bulb, the diagram plots the two curves in quadrant 1 on top of each other.

## Reload Data

## 4-Quadrant Diagram



The diagram shows the four quadrants:

- **Quadrant 1:** Plot of the fluid pressure of the sensing bulb versus the evaporator outlet temperature when the sensing bulb is attached to the evaporator outlet. In this image, the graph includes a second line that represents the vapor saturation curve of the refrigerant in the cycle, which is a plot of saturation pressure versus saturation temperature.
- **Quadrant 2:** Plot of the valve lift versus the evaporator outlet pressure. The valve lift is the position of the needle of the valve. As the evaporator outlet pressure decreases, the valve opens and valve lift increases.

When **Valve parameterization** is Tabulated data - quadrant diagram, the plot holds the evaporator outlet temperature constant at the **Reference evaporator outlet temperature** parameter value.

- **Quadrant 3:** Plot of the mass flow rate through the valve versus valve lift.

When **Valve parameterization** is Tabulated data - quadrant diagram, the plot holds the inlet pressure of the valve constant at the **Reference condenser outlet pressure** parameter, the inlet temperature constant at the **Reference condenser subcooling** parameter, and the outlet pressure constant at the **Reference evaporator outlet pressure parameter**.

- **Quadrant 4:** Plot of the mass flow rate through the valve versus evaporator outlet temperature.

When **Valve parameterization** is Tabulated data - quadrant diagram, the plot holds the inlet pressure of the valve constant at the **Reference condenser outlet pressure** parameter, the inlet temperature constant at the **Reference condenser subcooling** parameter, and the outlet pressure constant at the **Reference evaporator outlet pressure parameter**.

### Tabulated Data Parameterization

When you set **Valve parameterization** to Tabulated data - quadrant diagram, the block uses tabulated data. Three of the four curves in the thermostatic expansion valve quadrant diagram specify the valve characteristics. The supplier typically provides this diagram.

To determine block characteristics, the block performs interpolation on the data you provide in the parameters **Quadrant 1 - Evaporator outlet temperature vector**, **Quadrant 1 - Bulb pressure vector**, **Quadrant 2 - Valve lift vector**, **Quadrant 2 - Evaporator outlet pressure vector**, **Quadrant 3 - Valve lift vector**, and **Quadrant 3 - Mass flow rate vector**.

The block determines the mass flow rate through the valve from the inlet pressure, outlet pressure, equalization pressure, and sensing bulb temperature by using the data from quadrant 1 to quadrant 3 and a series of interpolations. The block first calculates the quadrant 2 evaporator outlet pressure as

$$p_{evap,Q2} = p_{eq} - p_{bulb}(T_{bulb}) + p_{bulb}(T_{evap,ref})$$

where:

- $p_{eq}$  depends on the valve pressure equalization setting:
  - When you set **Pressure equalization** to Internal pressure equalization,  $p_{eq}$  is the pressure at port **B**.
  - When you set **Pressure equalization** to External pressure equalization,  $p_{eq}$  is the pressure at port **E**.
- $p_{bulb}(T_{bulb})$  is the bulb fluid pressure interpolated at the bulb fluid temperature  $T_{bulb}$ . You specify the bulb fluid pressure data in the parameter **Quadrant 1 - Bulb pressure vector**.
- $p_{bulb}(T_{evap,ref})$  is the bulb fluid pressure interpolated at the reference evaporator outlet temperature  $T_{evap,ref}$ .

The block uses the valve lift data,  $L$ , from the **Quadrant 2 - Valve lift vector** parameter to interpolate the valve lift at the values in **Quadrant 2 - Evaporator outlet pressure vector**, which gives  $L = L(p_{evap,Q2})$ . The block then uses the reference mass flow rate,  $\dot{m}_{ref}$ , from the **Quadrant 3 - Mass flow rate vector**, to interpolate the mass flow rate at the valve lift values  $\dot{m}_{ref} = \dot{m}_{ref}(L)$ . The block scales the reference mass flow rate to the actual mass flow rate with

$$\dot{m} = \dot{m}_{ref} \frac{\sqrt{\frac{2}{v_{in}} \frac{\Delta p}{(\Delta p^2 - \Delta p_{lam}^2)^{0.25}}}}{\sqrt{\frac{2}{v_{ref}} (p_{cond,ref} - p_{evap,ref})}}$$

where:

- $p_{cond,ref}$  is the **Reference condenser outlet pressure** parameter.
- $p_{evap,ref}$  is the **Reference evaporator outlet pressure** parameter.
- $v_{ref}$  is the specific volume that corresponds to the **Reference condenser outlet pressure** and **Reference condenser subcooling** parameters.



- $v_{in}$  is the inlet specific volume, or the fluid volume per unit mass.
- $\Delta p$  is the pressure differential over the valve,  $p_A - p_B$ .
- $\Delta p_{lam}$  is the pressure threshold for transitional flow. Below this value, the flow is laminar. The block calculates this value as:

$$\Delta p_{lam} = \frac{p_A + p_B}{2}(1 - B_{lam}),$$

where  $B_{lam}$  is the value of the **Laminar flow pressure ratio** parameter.

### Pressure Equalization

The equalization pressure is the pressure at the evaporator outlet that governs valve operability. In physical systems with low pressure loss in the evaporator due to viscous friction, pressure equalization can occur internally with the pressure at port **B**. This is *internal pressure equalization*. In systems with larger losses, connect the evaporator outlet port to the valve block at port **E**.

### Bulb Temperature Dynamics

You can model the bulb dynamic response to changing temperatures by setting **Bulb temperature dynamics** to On. This introduces a first-degree lag in the measured temperature

$$\frac{dT_{bulb}}{dt} = \frac{T_S - T_{bulb}}{\tau_{bulb}},$$

where:

- $T_S$  is the temperature at port **S**. If you do not model bulb dynamics, this value is  $T_{bulb}$ .
- $\tau_{bulb}$  is the value of the **Bulb thermal time constant** parameter.

### Fluid Specific Volume Dynamics

When the fluid at the valve inlet is a liquid-vapor mixture, the block calculates the specific volume as

$$v_{in} = (1 - x_{dyn})v_{liq} + x_{dyn}v_{vap},$$

where:

- $x_{dyn}$  is the inlet vapor quality. The block applies a first-order lag to the inlet vapor quality of the mixture.
- $v_{liq}$  is the liquid specific volume of the fluid.
- $v_{vap}$  is the vapor specific volume of the fluid.

If the inlet fluid is liquid or vapor,  $v_{in}$  is the respective liquid or vapor specific volume.

### Vapor Quality Lag

If the inlet vapor quality is a liquid-vapor mixture, the block applies a first-order time lag

$$\frac{dx_{dyn}}{dt} = \frac{x_{in} - x_{dyn}}{\tau},$$

where:

- $x_{dyn}$  is the dynamic vapor quality.
- $x_{in}$  is the current inlet vapor quality.
- $\tau$  is the value of the **Inlet phase change time constant** parameter.

If the inlet fluid is a subcooled liquid,  $x_{dyn}$  is equal to  $x_{in}$ .

### Conservation Equations

Mass is conserved through the valve

$$\dot{m}_A + \dot{m}_B = 0,$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $\dot{m}_B$  is the mass flow rate at port **B**.

The block supports reversed flows numerically, however, the valve block is not designed for flows from port **B** to port **A**.

The block conserves energy flow through the valve

$$\Phi_A + \Phi_B = 0,$$

where:

- $\Phi_A$  is the energy flow rate at port **A**.
- $\Phi_B$  is the energy flow rate at port **B**.

## Ports

### Conserving

#### **A – Fluid inlet**

two-phase fluid

Valve inlet port. Connect this port to the outlet of a condenser or liquid receiver in a refrigeration cycle model.

#### **B – Fluid outlet**

two-phase fluid

Valve outlet port. Connect this port to the inlet of an evaporator in a refrigeration cycle model.

#### **S – Sensing bulb temperature measurement**

two-phase fluid

Two-phase fluid conserving port associated with the temperature of the sensing bulb. Connect this port to the outlet port of the evaporator. The valve operation depends on the comparison of the sensed temperature at **S** to the fluid saturation temperature.

There is no mass or energy flow rate through port **S**.

**E – Equalization line pressure measurement**

two-phase fluid

Two-phase fluid port associated with the pressure of the equalization line. Connect this port to the outlet port of the evaporator.

There is no mass or energy flow rate through port **E**.

**Dependencies**

To enable this port, set **Pressure equalization** to External pressure equalization.

**Parameters****Valve parameterization – Parameterization method**

Nominal capacity, superheat, and operating conditions (default) | Tabulated data - quadrant diagram

Method to determine valve characteristics. When you select **Nominal capacity, superheat, and operating conditions**, the valve provides the specified nominal capacity and superheat at the specified nominal operating conditions. When you select **Tabulated data - quadrant diagram**, you can specify the valve characteristics by using three of the four curves in a thermostatic expansion valve quadrant diagram.

**Capacity specification – Capacity specification method**

Evaporator heat transfer (default) | Mass flow rate

Method to specify capacity for the evaporator. When you select **Evaporator heat transfer**, you can specify the nominal and maximum evaporator heat transfer values. When you select **Mass flow rate**, the block calculates the heat transfer based on the mass flow rate.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Nominal capacity, superheat, and operating conditions**.

**Nominal evaporator heat transfer – Evaporator heat transfer rate in nominal conditions**

15 kW (default) | positive scalar

Rate of heat transfer in the system evaporator under nominal operating conditions. This parameter sets the operational conditions of the thermostatic expansion valve.

**Dependencies**

To enable this parameter, set **Valve parameterization** to **Nominal capacity, superheat, and operating conditions** and **Capacity specification** to **Evaporator Heat transfer**.

**Maximum evaporator heat transfer – Maximum evaporator heat transfer rate**

20 kW (default) | positive scalar

Maximum rate of heat transfer in the system evaporator. In most refrigeration cycles, this value is 20% to 50% larger than the value of the **Nominal evaporator heat transfer** parameter. This parameter sets the maximum operating conditions for the thermostatic expansion valve.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Capacity specification** to Evaporator Heat transfer.

**Nominal mass flow rate — Mass flow rate in nominal conditions**

0.005 kg/s (default) | positive scalar

Mass flow rate in the system evaporator under nominal operating conditions. The block uses this parameter to set the operational conditions of the thermostatic expansion valve.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Capacity specification** to Mass flow rate.

**Maximum mass flow rate — Maximum evaporator heat transfer rate**

0.008 kg/s (default) | positive scalar

Maximum rate of mass flow in the system evaporator. The block uses this parameter to set the maximum operating conditions for the thermostatic expansion valve.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Capacity specification** to Mass flow rate.

**Nominal pressure specification — Method to specify nominal pressure**

Specified pressure (default) | Pressure at specified saturation temperature

Method to specify nominal pressure for the evaporator and condenser. When you select **Specified pressure**, you can specify the evaporator and condenser outlet pressure. When you select **Pressure at specified saturation temperature**, you specify the saturation temperature in the condenser and evaporator. The block calculates the corresponding saturation temperatures by using the refrigerant property tables.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**Nominal condenser outlet pressure — Condenser outlet pressure in nominal conditions**

1.5 MPa (default) | positive scalar

Refrigerant pressure in the condenser under nominal operating conditions. The block calculates the corresponding saturation temperatures by using the refrigerant property tables.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Nominal pressure specification** to Specific pressure.

**Nominal evaporator outlet pressure — Evaporator outlet pressure in nominal conditions**

0.3 MPa (default) | positive scalar

Refrigerant pressure in the evaporator under nominal operating conditions. The block calculates the corresponding saturation temperatures by using the refrigerant property tables.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Nominal pressure specification** to Specific pressure.

#### Nominal condensing (saturation) temperature – Refrigerant saturation temperature in the condenser

313.15 K (default) | positive scalar

Refrigerant saturation temperature in the condenser under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Nominal pressure specification** to Pressure at specified saturation temperature.

#### Nominal evaporating (saturation) temperature – Evaporator saturation temperature in nominal conditions

273.15 K (default) | positive scalar

Refrigerant saturation temperature in the evaporator under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and **Nominal pressure specification** to Pressure at specified saturation temperature.

#### Nominal condenser subcooling – Operational condenser outlet temperature differential

5 deltaK (default) | positive scalar

Difference between the value of the **Nominal condensing (saturation) temperature** parameter and the liquid temperature at the condenser outlet under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

#### Nominal (static + opening) evaporator superheat – Operational evaporator outlet temperature differential

10 deltaK (default) | positive scalar

Difference between the superheated vapor temperature at the evaporator outlet and the value of the **Nominal evaporating (saturation) temperature** parameter under nominal operating conditions. The valve maintains this value by adjusting the open area to allow more or less fluid into the evaporator.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**Static (minimum) evaporator superheat – Minimum allowable temperature differential at evaporator outlet**

5 deltaK (default) | positive scalar

Minimum allowed difference between the superheated vapor temperature at the evaporator outlet and the value of the **Nominal evaporating (saturation) temperature** parameter. If the operational difference falls below this value, the valve is closes.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**MOP limit – Whether to enable pressure or temperature limits**

Off (default) | On - Specify maximum operating pressure | On - Specify maximum operating temperature

Whether to enable pressure limits in the evaporator. The options are:

- Off: There is no pressure limit. The valve opens and closes based only on the evaporator superheat.
- On - Specify maximum operating pressure: This setting places an upper limit on the evaporating pressure and temperature. The valve closes when the evaporator pressure reaches this limit.
- On - Specify maximum operating temperature: This setting places an upper limit on the evaporating pressure and temperature. The valve closes when the evaporator temperature reaches this limit.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**Maximum evaporator outlet pressure – Maximum pressure**

0.5 MPa (default) | positive scalar

Maximum permissible saturation pressure in the evaporator when evaporator pressure limiting is on.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and set **MOP limit** to On - Specify maximum operating pressure.

**Maximum evaporating (saturation) temperature – Maximum temperature**

288.15 K (default) | positive scalar

Maximum permissible saturation temperature in the evaporator when evaporator temperature limiting is on.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions and set **MOP limit** to On - Specify maximum operating temperature.

**Closed valve leakage as a fraction of nominal flow – Minimum flow through valve at all times**

1e-6 (default) | positive scalar

Fraction of leakage-to-nominal flow through the valve when the valve is closed. A nonzero value enhances numerical stability in the fluid network.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Nominal capacity, superheat, and operating conditions.

**Quadrant 1 – Evaporator outlet temperature vector – Vector of temperature values at evaporator outlet**

0 : 10 : 40 degC (default) | vector

Temperature of the sensing bulb, which is typically placed at the evaporator outlet. Therefore, this parameter is equivalent to the evaporator outlet temperature. The block uses this data on the x-axis in quadrant 1 of the four-quadrant diagram. This parameter must be the same length as the **Quadrant 1 - Bulb pressure vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

**Quadrant 1 – Bulb pressure vector – Vector of pressure values of fluid inside sensing bulb**

0.3 : 0.1 : 0.7 MPa (default) | vector

Pressure of the fluid inside the sensing bulb at the evaporator outlet. The refrigerant pressure at the evaporator outlet is independent of the internal fluid pressure of the sensing bulb. The valve uses the bulb pressure to open. The block interpolates this data for the y-axis in quadrant 1 of the four-quadrant diagram. This parameter must be the same length as the **Quadrant 1 - Evaporator outlet temperature vector** parameter.

**Dependencies**

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

**Quadrant 2 – Valve lift vector – Vector of valve lift values**

0 : 0.15 : 0.6 mm (default) | vector

Vector of the valve lift, or the position of the needle of the valve. The block uses this data on the x-axis in quadrant 2 of the four-quadrant diagram. The valve lift must be defined consistently between quadrants 2 and 3. The block uses valve lift to relate the pressure in quadrant 2 and flow rate in quadrant 3. If data is unavailable, you can construct valve lift values, such as 0 for fully closed and 1 for fully open. This parameter must be the same length as the **Quadrant 2 - Evaporator outlet pressure vector** parameter.

#### Dependencies

To enable this parameter, set **Valve parameterization** to **Tabulated data – quadrant diagram**.

#### Quadrant 2 – Evaporator outlet pressure vector – Vector of values of evaporator outlet pressure

0.3 : -0.05 : 0.1 MPa (default) | vector

Vector of the equalization pressure, which is the measure of the evaporator outlet pressure of the valve. The valve uses the equalization pressure to close:

- If the valve has internal pressure equalization, this parameter is the pressure at the outlet of the valve, which is connected to the evaporator inlet. In this case, the block assumes that the pressure loss in the evaporator is small.
- If the valve has external pressure equalization, this is the value measured by the external pilot line connected to the evaporator outlet.

The block interpolates this data for the y-axis in quadrant 2 of the four-quadrant diagram. This parameter must be the same length as the **Quadrant 2 - Valve lift vector** parameter.

#### Dependencies

To enable this parameter, set **Valve parameterization** to **Tabulated data – quadrant diagram**.

#### Quadrant 3 – Valve lift vector – Vector of valve lift values

0 : 0.15 : 0.6 mm (default) | vector

Vector of the valve lift, or the position of the needle of the valve. The block uses this data on the x-axis in quadrant 3 of the four-quadrant diagram. The valve lift must be defined consistently between quadrants 2 and 3. The block uses valve lift to relate the pressure in quadrant 2 and flow rate in quadrant 3. If data is unavailable, you can construct valve lift values, such as 0 for fully closed and 1 for fully open. This parameter must be the same length as the **Quadrant 3 - Mass flow rate vector** parameter.

#### Dependencies

To enable this parameter, set **Valve parameterization** to **Tabulated data – quadrant diagram**.

#### Quadrant 3 – Mass flow rate vector – Vector of values of mass flow rate through the valve

[1e-7, 0.015 : 0.015 : 0.06] kg/s (default) | vector

Values of mass flow rate through the valve in relation to different values of the valve opening. The block interpolates this data for the y-axis in quadrant 3 of the four-quadrant diagram. This parameter must be the same length as the **Quadrant 3 - Valve lift vector** parameter. The first element



corresponds to the leakage mass flow rate when the valve is closed. This value must be a positive, small value for numerical robustness.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

#### Reference condenser outlet pressure – Reference pressure of condenser outlet

2 MPa (default) | scalar

Reference valve inlet pressure. The block holds the valve inlet pressure at this value in quadrant 3 of the four-quadrant diagram.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

#### Reference evaporator outlet pressure – Reference pressure of evaporator outlet

0.3 MPa (default) | scalar

Reference evaporator outlet pressure. The block holds the evaporator outlet pressure at this value in quadrant 3 of the four-quadrant diagram.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

#### Reference evaporator outlet temperature – Reference temperature of evaporator outlet

0 degC (default) | scalar

Reference evaporator outlet temperature. The block holds the evaporator outlet temperature at this value in quadrant 2 of the four-quadrant diagram.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

#### Reference condenser subcooling – Reference condenser outlet temperature differential

5 deltaK (default) | scalar

Difference in temperature between the condenser outlet and the condensing temperature. The block holds the valve inlet temperature at this value in quadrant 3 of the four-quadrant diagram.

#### Dependencies

To enable this parameter, set **Valve parameterization** to Tabulated data – quadrant diagram.

#### Pressure equalization – Pressure measurement location

Internal pressure equalization (default) | External pressure equalization

Pressure measurement location. Set this parameter to Internal pressure equalization to measure the evaporator pressure at port **B**. Set this parameter to External pressure

equalization to expose the evaporator pressure port, **E**. Connect this port to an evaporator outlet. Choose the setting for this parameter depending on the design of your thermostatic expansion valve.

### **Bulb temperature dynamics — Whether to model thermal lag**

Off (default) | On

Whether to model thermal dynamics in temperature measurement. When you set this parameter to On, the bulb fluid temperature lags the refrigeration temperature. The **Bulb thermal time constant** parameter determines the lag response.

### **Bulb thermal time constant — Thermal lag time constant**

20 s (default) | positive scalar

First-order time constant for the bulb fluid temperature delay. The block delays the measured temperature relative to the refrigerant temperature at port **S**. The time constant is proportional to the thermal mass of the bulb, including any ballast, and is inversely proportional to the thermal conductance across the thermal contact surface.

#### **Dependencies**

To enable this parameter, set **Bulb temperature dynamics** to On.

### **Cross-sectional area at ports A and B — Port area**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area of connecting pipes at ports **A** and **B**.

### **Laminar flow pressure ratio — Ratio of evaporator pressures at flow regime transition**

0.999 (default) | positive scalar

Ratio of the evaporator outlet pressure to evaporator inlet pressure at which the fluid transitions between the laminar and turbulent regimes. The pressure loss corresponds to the mass flow rate linearly in laminar flows and quadratically in turbulent flows.

### **Inlet phase change time constant — Lag for mixture specific volume**

0.1 s (default) | positive scalar

Time lag for liquid-vapor mixtures in computing the fluid specific volume. This parameter does not influence the specific volume when the inlet fluid is a fully supercooled liquid.

## **Version History**

### **Introduced in R2020b**

#### **Block supports parameterization by tabulated data from a 4-Quadrant diagram**

You can set the new **Valve parameterization** parameter to:

- Nominal capacity, superheat, and operating conditions — The block behaves as in previous releases.
- Tabulated data - quadrant diagram — The block enables parameters that you use to specify the curves in a 4-Quadrant diagram.

Additionally, you can generate a plot of the diagram by right-clicking the block and selecting **Fluids > Plot 4-Quadrant Diagram**.

## References

- [1] Eames, Ian W., Adriano Milazzo, and Graeme G. Maidment. "Modelling Thermostatic Expansion Valves." *International Journal of Refrigeration* 38 (February 2014): 189-97.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

System-Level Condenser Evaporator (2P-MA)

## Turbine (G)

Gas turbine in a thermodynamic cycle

**Library:** Simscape / Fluids / Gas / Turbomachinery



### Description

The Turbine (G) block models a turbine in a gas network. You can parameterize the block as a tabulated turbine map that is either a 1-D function of pressure ratio or 2-D function of pressure ratio and corrected mass flow rate. Fluid flowing from port **A** to port **B** generates torque. Port **R** reports shaft torque and angular velocity relative to port **C**, which represents the turbine casing.

Port **VN** represents the vane opening fraction. This value linearly scales the corrected mass flow rate but does not influence the turbine efficiency. A value of 1 corresponds to the data in the turbine map.

### Turbine Map

To visualize the block map, right-click the block and select **Fluids > Plot Turbine Map**.

Each time you modify the block settings, click **Reload Data** on the figure window.

The turbine map relates turbine performance, as a function of pressure ratio, to the corrected mass flow rate and isentropic efficiency. The pressure ratio is the ratio between the turbine inlet pressure and outlet pressure.

The turbine map plots two separate graphs: corrected mass flow rate versus pressure ratio and isentropic efficiency versus pressure ratio. When you set the **Turbine map parameterization** to **Tabulated data - flow rate and efficiency vs. corrected speed and pressure ratio**, the plots also depend on the corrected rotor speed,  $N$ . The indexing variable  $\beta$  does not need to be the same between the mass flow rate and efficiency tables.

### Corrected Mass Flow Rate

Due to the large changes in pressure and temperature inside a turbine, the turbine map plots performance in terms of the corrected mass flow rate. The block adjusts the corrected mass flow rate from the inlet mass flow rate by using a corrected pressure and temperature

$$\dot{m}_A \sqrt{\frac{T_A}{T_{corr}}} = \dot{m}_{corr} \frac{p_A}{p_{corr}},$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.
- $T_A$  is the temperature at port **A**.
- $T_{corr}$  is the **Reference temperature for corrected flow** parameter. Refer to the data sheet for your turbine for this value.
- $\dot{m}_{corr}$  is the corrected mass flow rate.

When **Turbine map parameterization** is Analytical - nominal pressure ratio and corrected mass flow rate, this is the value of the **Nominal corrected mass flow rate** parameter.

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. pressure ratio, this is the value of the **Corrected mass flow rate vector,  $\dot{m}(\text{pr})$**  parameter.

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio, this is the value of the **Corrected mass flow rate table,  $\dot{m}(\text{N},\text{beta})$**  parameter.

- $p_A$  is the pressure at port **A**.
- $p_{corr}$  is the **Reference pressure for corrected flow** parameter. Refer to the data sheet for your turbine for this value.

### Corrected Speed

The block also adjusts the shaft speed,  $\omega$ , according to the reference temperature, such that the corrected shaft speed is

$$\omega_{corr} = \frac{\omega}{\sqrt{\frac{T_A}{T_{ref}}}}$$

### Shaft Torque

The block calculates the shaft torque,  $\tau$ , as

$$\tau = \frac{\eta_m \dot{m}_A \Delta h_{total}}{\omega}$$

where:

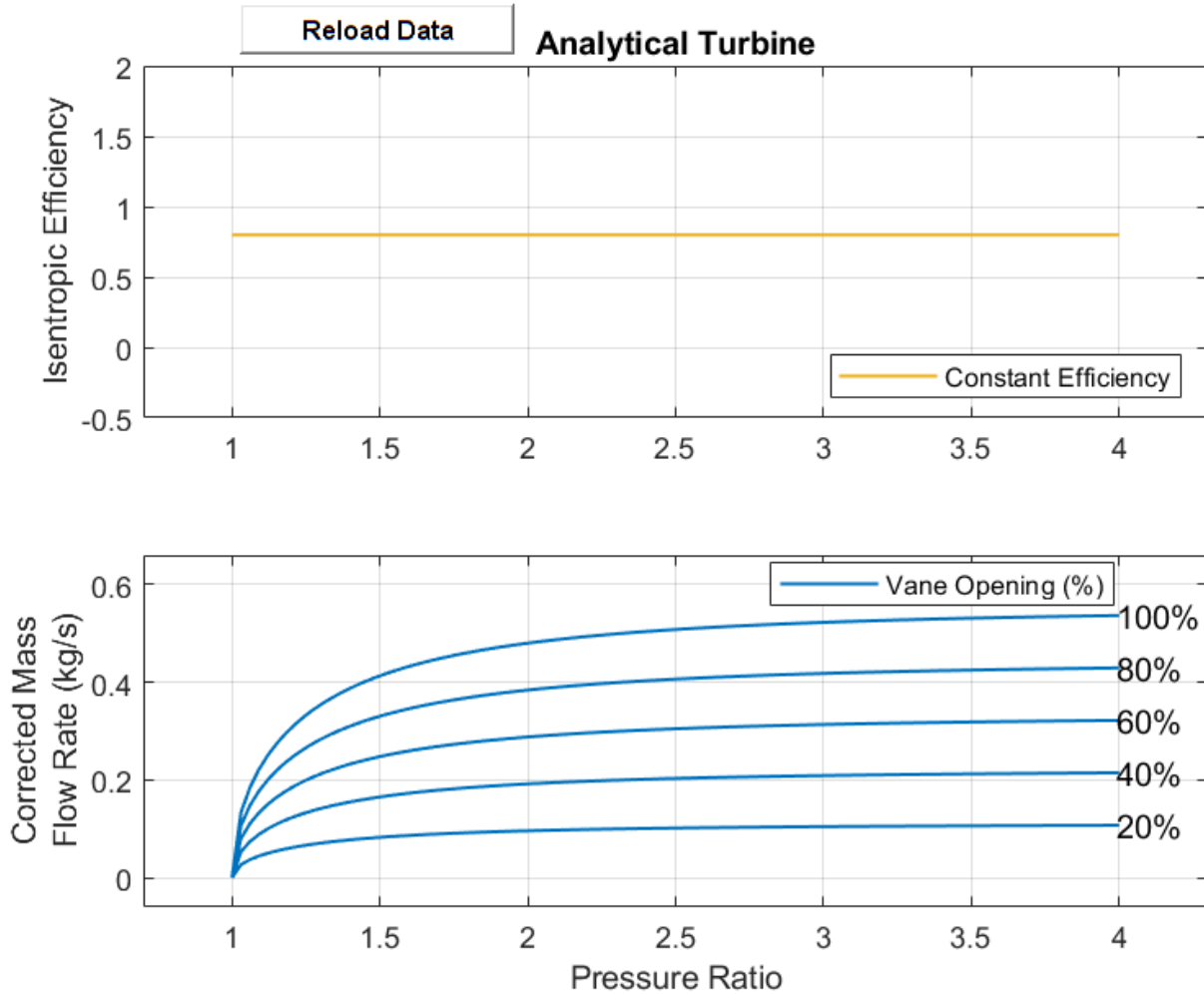
- $\Delta h_{total}$  is the total change in the fluid specific enthalpy.
- $\eta_m$  is the value of the **Mechanical efficiency** parameter.
- $\omega$  is the relative shaft angular velocity,  $\omega_R - \omega_C$ .

Reversed flow, from port **B** to port **A**, is outside of the typical turbine operation mode and may not return accurate results. A threshold region when flow approaches zero ensures the block generates no torque when the flow rate is near zero or reversed.

### Analytical Parametrization

Use the analytical parametrization to create a turbine based on the expected nominal operating conditions. When **Turbine map parameterization** is Analytical – nominal pressure ratio and corrected mass flow rate, the turbine isentropic efficiency is constant and the mass flow rate is a function of the pressure ratio.

This image shows the default turbine map when you use the analytical parameterization.

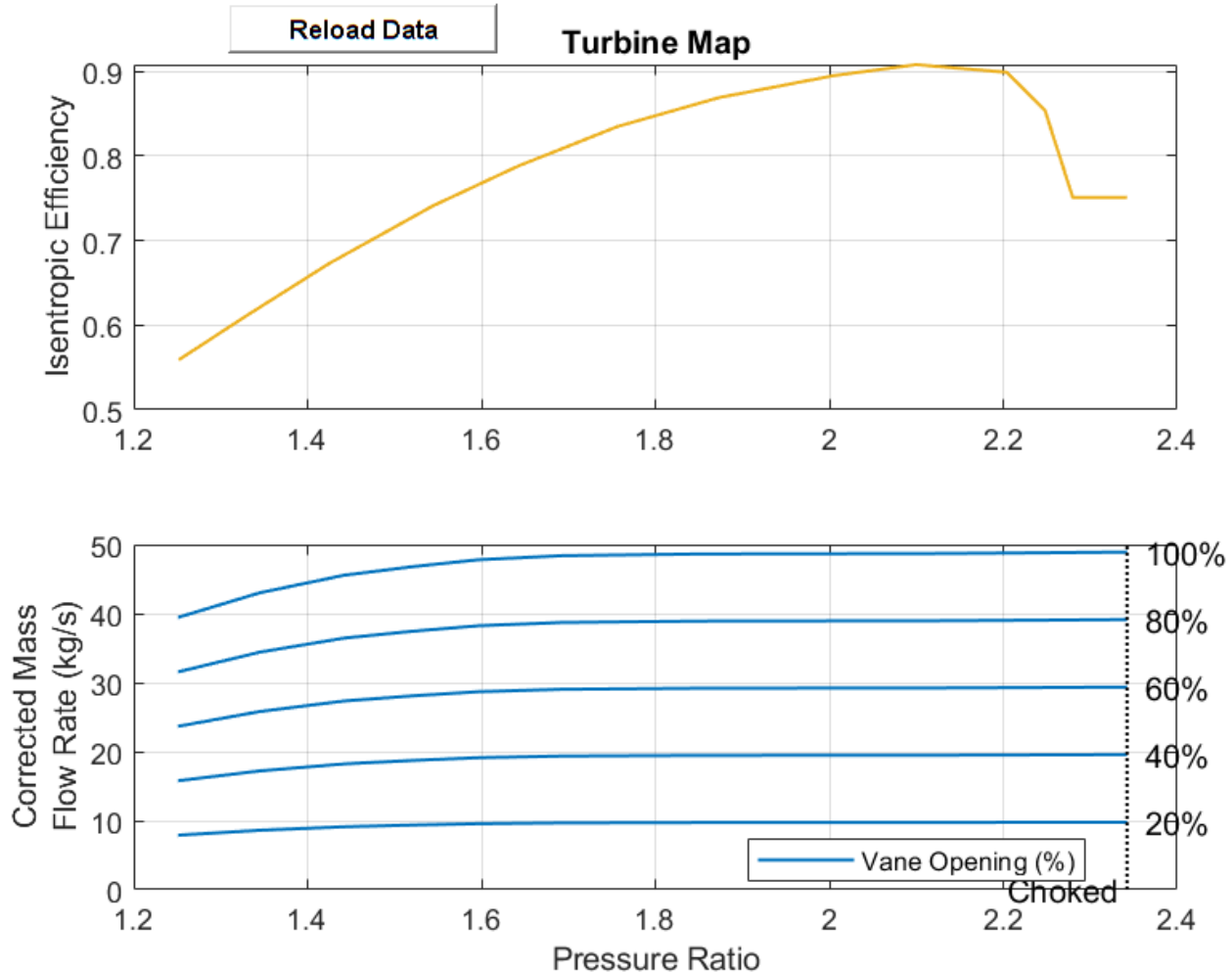


### Parameterization by Pressure Ratio

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. pressure ratio, the turbine isentropic efficiency and mass flow rate are a function of the pressure ratio and do not account for any changes in the turbine rotational speed.

The last element of the **Corrected mass flow rate vector,  $\dot{m}(\text{pr})$**  and the **Pressure ratio vector,  $\text{pr}$**  parameters represents the corrected mass flow rate and pressure ratio at choked flow conditions.

This image shows the default turbine map when you use the 1-D parameterization.

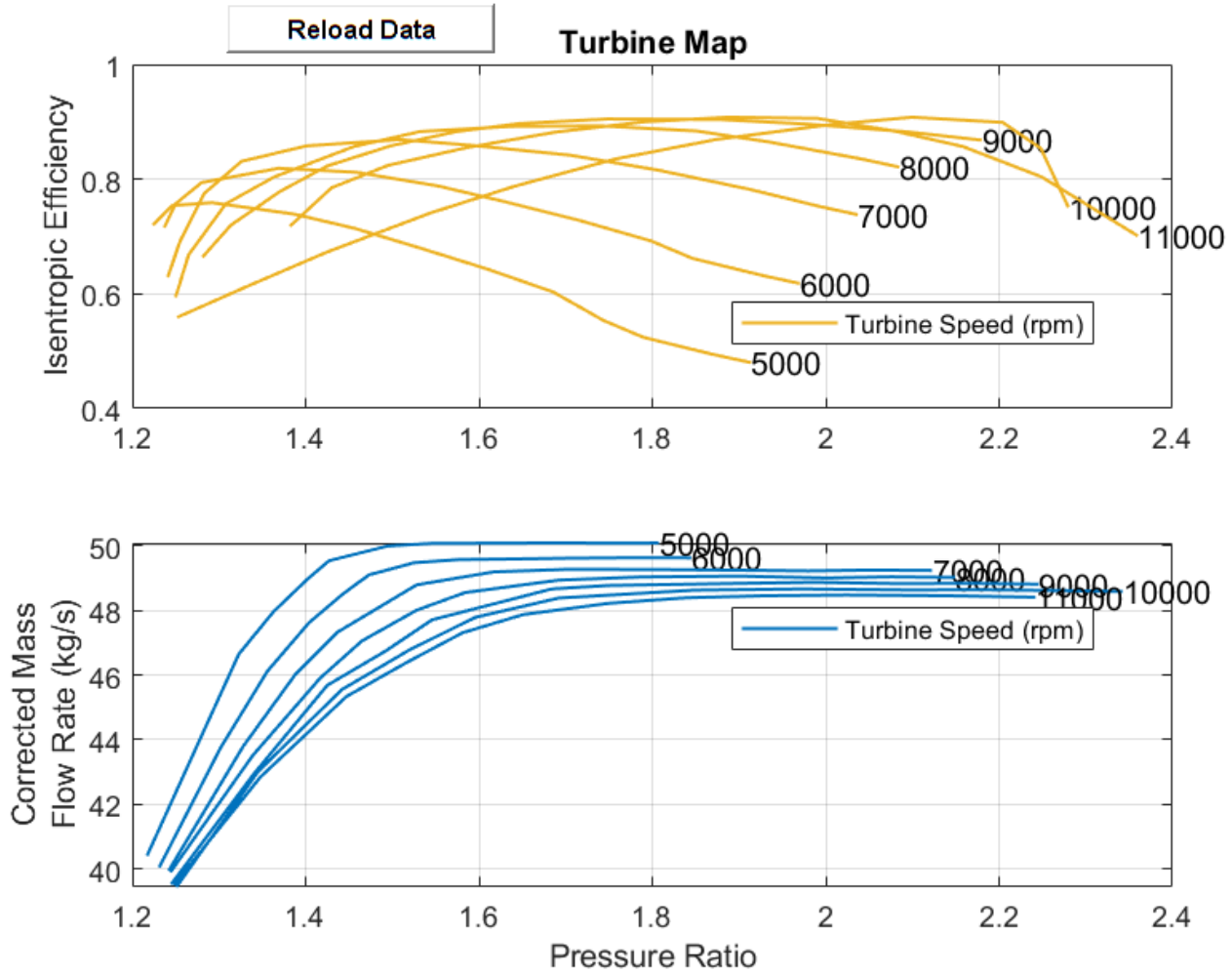


### Parameterization by Pressure Ratio and Corrected Mass Flow Rate

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio, the turbine isentropic efficiency, pressure ratio, and corrected mass flow rate are a function of the corrected speed,  $N$ , and the map index,  $\beta$ . The block uses linear interpolation between data points for the efficiency, pressure ratio, and corrected mass flow rate parameters.

The last column of the **Corrected mass flow rate table,  $\dot{m}(N,\beta)$**  and the **Pressure ratio table,  $pr(N,\beta)$**  parameters represents the corrected mass flow rate and pressure ratio at choked flow conditions.

This image shows the default turbine map when you use the 2-D parameterization.



### Continuity Equations

Mass is preserved over the block:

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_B$  is the mass flow rate at port **B**.

The block calculates the energy balance as

$$\Phi_A + \Phi_B - P_{fluid} = 0,$$

where:

- $\Phi_A$  is the energy flow rate at port **A**.
- $\Phi_B$  is the energy flow rate at port **B**.
- $P_{fluid}$  is the work done by the fluid, which the block determines from the change in total fluid specific enthalpy,  $P_{fluid} = \dot{m}_A \Delta h_{total}$ .



## Assumptions and Limitations

- The shaft does not rotate under reversed flow conditions. Results during reversed flows may not be accurate.

## Ports

### Input

#### **VN – Vane opening fraction, unitless**

physical signal

Vane opening fraction, specified as a unitless physical signal. The corrected mass flow rate scales linearly with the value of **VN**. A fraction of 1 corresponds to the tabulated data. The vane opening fraction does not influence the isentropic efficiency.

### Conserving

#### **A – Gas inlet**

gas

Gas conserving port associated with the fluid entry port.

#### **B – Gas outlet**

gas

Gas conserving port associated with the fluid exit port.

#### **C – Turbine case**

mechanical translational

Port associated with the turbine casing.

#### **R – Turbine shaft**

mechanical translational

Port associated with the turbine shaft torque and angular velocity.

## Parameters

### Parameterization

#### **Turbine map parameterization – Performance parameterization**

Analytical - Nominal pressure ratio and corrected mass flow rate (default) |  
 Tabulated data - Flow rate and efficiency vs. pressure ratio | Tabulated data -  
 Flow rate and efficiency vs. corrected speed and pressure ratio

Performance parameterization specification:

- Analytical - Nominal pressure ratio and corrected mass flow rate: Parameterize turbine isentropic efficiency and corrected mass flow rate analytically.
- Tabulated data - Flow rate and efficiency vs. pressure ratio: Parameterize turbine isentropic efficiency and corrected mass flow rate by pressure ratio.

- Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio: Parameterize turbine isentropic efficiency and corrected mass flow rate by corrected speed and pressure ratio.

**Minimum vane opening – Minimum opening fraction**

1e-3 (default) | positive scalar in the range (0,1]

Minimum vane opening fraction. This value is the lower boundary to the signal at **VN**. The block multiplies the value of this parameter by the mass flow rate to obtain the minimum corrected mass flow rate through the turbine.

**Maximum vane opening – Maximum opening fraction**

1 (default) | positive scalar in the range (0,1]

Maximum vane opening. This value is the upper boundary to the signal at **VN**. The block multiplies the value of this parameter by the mass flow rate to obtain the maximum corrected mass flow rate through the turbine.

**Corrected speed index vector, N – Tabulated data shaft speed indices**

100 .\* [50, 60, 70, 80, 90, 100, 110] rpm (default) | vector of positive scalars

Vector of constant shaft speeds for tabular parameterization of corrected mass flow rate and isentropic efficiency.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

**Flow Rate Data****Nominal pressure ratio – Pressure ratio value**

2 (default) | positive scalar

Pressure ratio value under nominal operating conditions for the analytical parameterization.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

**Nominal corrected mass flow rate – Corrected mass flow rate value**

48 kg/s (default) | positive scalar

Corrected mass flow rate value under nominal operating conditions for the analytical parameterization.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

**Pressure ratio vector, pr – Vector of pressure ratios**

[1.251, 1.345, 1.442, 1.521, 1.596, 1.692, 1.849, 1.972, 2.1, 2.173, 2.259, 2.3424] (default) | vector of positive scalars

Vector of pressure ratio values for the tabulated parameterization of corrected mass flow rate. This vector must have the same number of elements as the **Corrected mass flow rate vector,  $\dot{m}(pr)$**  parameter and all elements must be greater than 1. The last element must be the pressure ratio at choked conditions.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

#### Corrected mass flow rate vector, $\dot{m}(pr)$ – Vector of corrected mass flow rate values

[39.439, 43.01, 45.556, 46.801, 47.792, 48.388, 48.634, 48.67, 48.689, 48.747, 48.825, 48.912] kg/s (default) | vector of positive scalars

Vector of corrected mass flow rate values for the tabulated parameterization of corrected mass flow rate. This vector must have the same number of elements as the **Pressure ratio vector,  $pr$**  parameter and all elements must be greater than 0. The last element must be the corrected mass flow rate at choked conditions.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

#### Pressure ratio table, $pr(N, \beta)$ – Turbine map pressure ratio data

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Corrected speed index vector,  $N$**  parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[1.217, 1.285, 1.323, 1.363, 1.402, 1.427, 1.495, 1.545, 1.6, 1.687, 1.747, 1.8074; 1.231, 1.302, 1.356, 1.404, 1.443, 1.473, 1.525, 1.577, 1.635, 1.709, 1.782, 1.845; 1.242, 1.328, 1.388, 1.437, 1.528, 1.617, 1.704, 1.811, 1.915, 1.979, 2.053, 2.1226; 1.244, 1.339, 1.417, 1.465, 1.528, 1.584, 1.692, 1.787, 1.899, 2, 2.075, 2.1492; 1.245, 1.34, 1.425, 1.492, 1.546, 1.684, 1.748, 1.882, 1.987, 2.084, 2.167, 2.2458; 1.251, 1.345, 1.442, 1.521, 1.596, 1.692, 1.849, 1.972, 2.1, 2.173, 2.259, 2.3424; 1.248, 1.348, 1.447, 1.516, 1.581, 1.651, 1.749, 1.839, 1.93, 2.024, 2.154, 2.242]

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

#### Corrected mass flow rate table, $\dot{m}(N, \beta)$ – Turbine map corrected mass flow rate data

*M*-by-*N* matrix (default)

$M$ -by- $N$  matrix of corrected mass flow rates at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Constant speed index vector**,  $N$  parameter.
- $N$  is the number of  $\beta$  indices in the table.

The default table values are:

[40.403, 44.417, 46.653, 47.966, 48.97, 49.544, 50.001, 50.081, 50.086, 50.095, 50.09, 50.0922; 40.044, 43.754, 46.125, 47.626, 48.513, 49.105, 49.481, 49.58, 49.597, 49.624, 49.638, 49.633; 39.941, 43.795, 46.017, 47.335, 48.795, 49.199, 49.279, 49.27, 49.248, 49.23, 49.255, 49.2428; 39.896, 43.512, 45.914, 47.061, 48.011, 48.558, 48.943, 49.042, 49.069, 49.01, 49.046, 49.0266; 39.524, 42.934, 45.686, 46.743, 47.715, 48.67, 48.777, 48.836, 48.876, 48.836, 48.845, 48.8184; 39.439, 43.01, 45.556, 46.801, 47.792, 48.388, 48.634, 48.67, 48.639, 48.647, 48.625, 48.5912; 39.502, 42.849, 45.336, 46.385, 47.312, 47.877, 48.222, 48.397, 48.459, 48.482, 48.455, 48.414] kg/s

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

#### Efficiency Data

##### Constant isentropic efficiency – Isentropic efficiency value

0.8 (default) | positive scalar

Isentropic efficiency under nominal operating conditions for the analytical parametrization.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

##### Pressure ratio vector, pr – Vector of pressure ratios

[1.252, 1.328, 1.425, 1.544, 1.642, 1.757, 1.873, 2.005, 2.1, 2.204, 2.248, 2.28] (default) | vector of positive scalars

Vector of pressure ratio values for the tabulated parameterization of isentropic efficiency. This vector must have the same number of elements as the **Isentropic efficiency vector, eta(pr)** parameter and all elements must be greater than 1.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

##### Isentropic efficiency vector, eta(pr) – Vector of isentropic efficiencies

[.559, .61, .673, .741, .788, .835, .869, .895, .908, .899, .854, .751] (default) | vector of elements in the range (0,1)

Vector of isentropic efficiency values for the tabulated parameterization of isentropic efficiency. This vector must have the same number of elements as the **Pressure ratio vector, pr** parameter and all elements must be greater than 0 and less than or equal to 1.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

#### Pressure ratio table, pr(N,beta) – Turbine map pressure ratio data

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Constant speed index vector, N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[1.224, 1.246, 1.292, 1.387, 1.457, 1.534, 1.61, 1.686, 1.743, 1.79, 1.871, 1.914; 1.237, 1.25, 1.28, 1.369, 1.459, 1.553, 1.629, 1.716, 1.799, 1.846, 1.927, 1.97; 1.241, 1.255, 1.283, 1.326, 1.401, 1.509, 1.591, 1.704, 1.806, 1.913, 1.994, 2.037; 1.25, 1.265, 1.308, 1.364, 1.456, 1.532, 1.637, 1.739, 1.851, 1.934, 2.042, 2.085; 1.281, 1.314, 1.371, 1.425, 1.498, 1.574, 1.647, 1.749, 1.878, 1.979, 2.091, 2.18; 1.252, 1.328, 1.425, 1.544, 1.642, 1.757, 1.873, 2.005, 2.1, 2.204, 2.248, 2.28; 1.382, 1.43, 1.495, 1.586, 1.688, 1.791, 1.887, 1.99, 2.079, 2.158, 2.249, 2.217]

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

#### Isentropic efficiency table, eta(N,beta) – Turbine map isentropic efficiency data

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine isentropic efficiencies at the specified constant shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Constant speed index vector, N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[.72, .754, .759, .739, .714, .679, .643, .603, .554, .524, .494, .48; .716, .757, .794, .819, .812, .788, .761, .728, .692, .662, .632, .618; .629, .691, .775, .831, .858, .869, .859, .842, .816, .782, .752, .738; .594, .668, .757, .804, .857, .883, .892, .893, .884, .865, .835, .821; .664, .72, .779, .823, .858, .883, .897, .905, .904, .896, .883, .868; .559, .61, .673, .741, .788, .835, .869, .895, .908, .899, .854, .751; .718, .785, .824, .855, .882, .9, .908, .906, .884, .857, .804, .701]

### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

### Reference Data

#### Reference pressure for corrected flow — Correcting pressure

0.101325 MPa (default) | positive scalar

Pressure at which the turbine data consolidates to a corrected trend line.

#### Reference temperature for corrected flow — Correcting temperature

288.15 K (default) | positive scalar

Temperature at which the turbine data the turbine data consolidates to a corrected trend line.

#### Mechanical efficiency — Efficiency of conversion to torque

0.9 (default) | positive scalar in the range [0,1]

Efficiency of the conversion from reduction in specific enthalpy to shaft torque.

#### Inlet area at port A — Turbine inlet area

1 m<sup>2</sup> (default) | positive scalar

Turbine inlet cross-sectional area.

#### Outlet area at port B — Turbine outlet area

1 m<sup>2</sup> (default) | positive scalar

Turbine outlet cross-sectional area.

## Version History

Introduced in R2021a

### Block supports nominal parameterization

Now you can parameterize the block using nominal values. Set **Turbine map parameterization** to Analytical - nominal pressure ratio and corrected mass flow rate. This selection enables these new parameters:

- **Nominal pressure ratio**
- **Nominal corrected mass flow rate**

## References

- [1] Kurzke, Joachim. "How to Get Component Maps for Aircraft Gas Turbine Performance Calculations." *Volume 5: Manufacturing Materials and Metallurgy; Ceramics; Structures and Dynamics; Controls, Diagnostics and Instrumentation; Education; General*, American Society of Mechanical Engineers, 1996, p. V005T16A001.

[2] Plencner, Robert M. "Plotting component maps in the Navy/NASA Engine Program (NNEP): A method and its usage." *NASA Technical Memorandum*, 1989.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Compressor (G)

### **Topics**

"Brayton Cycle (Gas Turbine)"

## Turbine (2P)

Two-phase turbine in a thermodynamic cycle

**Library:** Simscape / Fluids / Two-Phase Fluid / Fluid Machines



### Description

The Turbine (2P) block models a turbine in a two-phase fluid network. You can parameterize the block as a tabulated turbine map that is either a 1-D function of pressure ratio or 2-D function of pressure ratio and corrected mass flow rate. Fluid flowing from port **A** to port **B** generates torque. Port **R** reports shaft torque and angular velocity relative to port **C**, which represents the turbine casing.

Port **VN** represents the vane opening fraction. This value linearly scales the corrected mass flow rate but does not influence the turbine efficiency. A value of 1 corresponds to the data in the turbine map.

The Turbine (2P) block assumes that superheated fluid enters the inlet. You can use the **Report when fluid is not fully vapor** parameter to choose what the block does when the fluid does not meet superheated conditions.

### Turbine Map

To visualize the block map, right-click the block and select **Fluids > Plot Turbine Map**.

Each time you modify the block settings, click **Reload Data** on the figure window.

The turbine map relates turbine performance, as a function of pressure ratio, to the corrected mass flow rate and isentropic efficiency. The pressure ratio is the ratio between the turbine inlet pressure and outlet pressure.

The turbine map plots two separate graphs: corrected mass flow rate versus pressure ratio and isentropic efficiency versus pressure ratio. When you set the **Turbine map parameterization** to **Tabulated data - flow rate and efficiency vs. corrected speed and pressure ratio**, the plots also depend on the corrected rotor speed,  $N$ . The indexing variable  $\beta$  does not need to be the same between the mass flow rate and efficiency tables.

### Corrected Mass Flow Rate

Due to the large changes in pressure and temperature inside a turbine, the turbine map plots performance in terms of the corrected mass flow rate. The block adjusts the corrected mass flow rate from the inlet mass flow rate by using a corrected pressure and temperature

$$\dot{m}_A \sqrt{\frac{T_A}{T_{corr}}} = \dot{m}_{corr} \frac{p_A}{p_{corr}},$$

where:

- $\dot{m}_A$  is the mass flow rate at port **A**.



- $T_A$  is the temperature at port **A**.
- $T_{corr}$  is the **Reference temperature for corrected flow** parameter. Refer to the data sheet for your turbine for this value.
- $\dot{m}_{corr}$  is the corrected mass flow rate.

When **Turbine map parameterization** is Analytical - nominal pressure ratio and corrected mass flow rate, this is the value of the **Nominal corrected mass flow rate** parameter.

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. pressure ratio, this is the value of the **Corrected mass flow rate vector,  $\dot{m}(pr)$**  parameter.

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio, this is the value of the **Corrected mass flow rate table,  $\dot{m}(N,\beta)$**  parameter.

- $p_A$  is the pressure at port **A**.
- $p_{corr}$  is the **Reference pressure for corrected flow** parameter. Refer to the data sheet for your turbine for this value.

### Corrected Speed

The block also adjusts the shaft speed,  $\omega$ , according to the reference temperature, such that the corrected shaft speed is

$$\omega_{corr} = \frac{\omega}{\sqrt{\frac{T_A}{T_{ref}}}}$$

### Shaft Torque

The block calculates the shaft torque,  $\tau$ , as

$$\tau = \frac{\eta_m \dot{m}_A \Delta h_{total}}{\omega}$$

where:

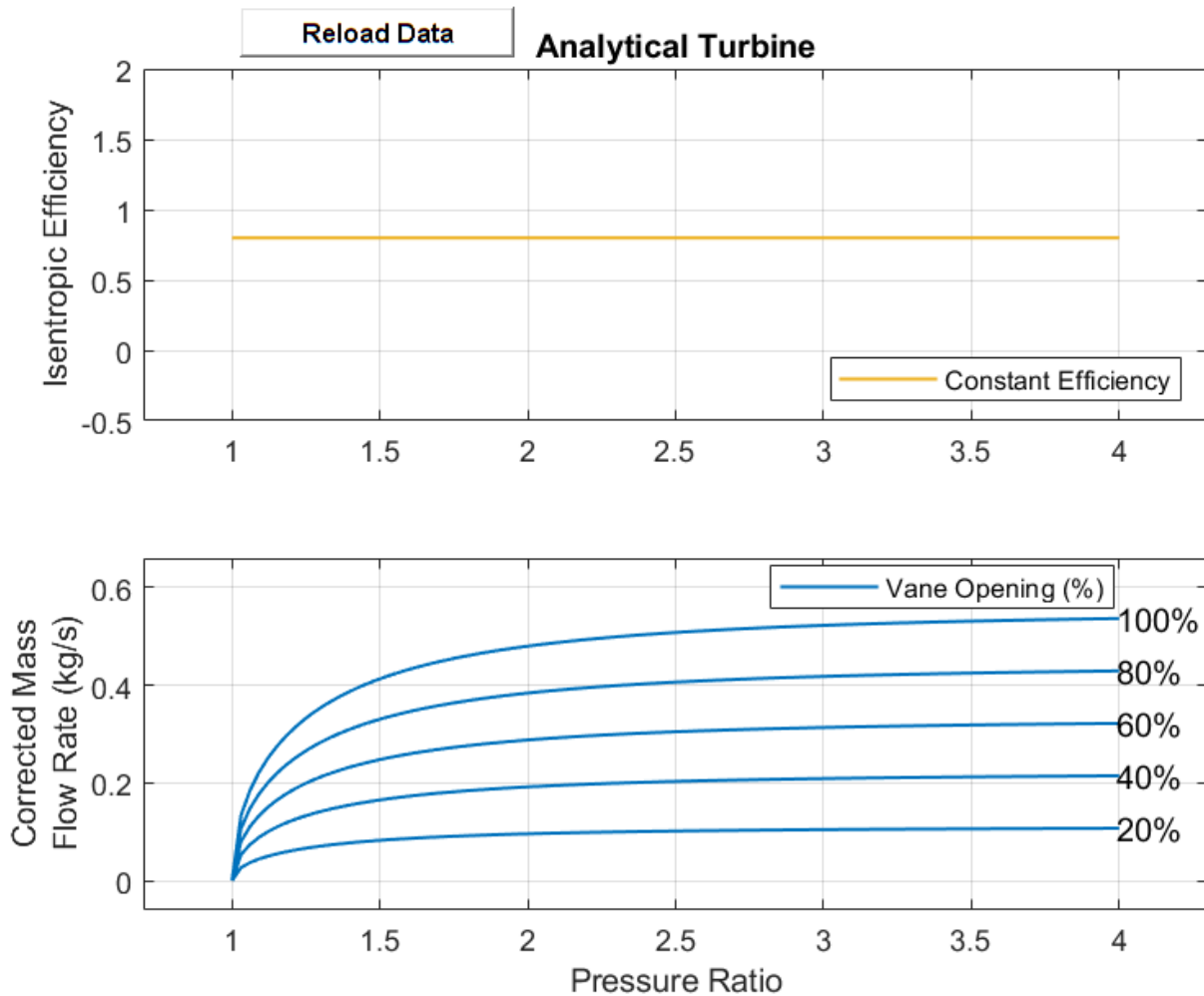
- $\Delta h_{total}$  is the total change in the fluid specific enthalpy.
- $\eta_m$  is the value of the **Mechanical efficiency** parameter.
- $\omega$  is the relative shaft angular velocity,  $\omega_R - \omega_C$ .

Reversed flow, from port **B** to port **A**, is outside of the typical turbine operation mode and may not return accurate results. A threshold region when flow approaches zero ensures the block generates no torque when the flow rate is near zero or reversed.

### Analytical Parametrization

Use the analytical parametrization to create a turbine based on the expected nominal operating conditions. When **Turbine map parameterization** is Analytical – nominal pressure ratio and corrected mass flow rate, the turbine isentropic efficiency is constant and the mass flow rate is a function of the pressure ratio.

This image shows the default turbine map when you use the analytical parameterization.

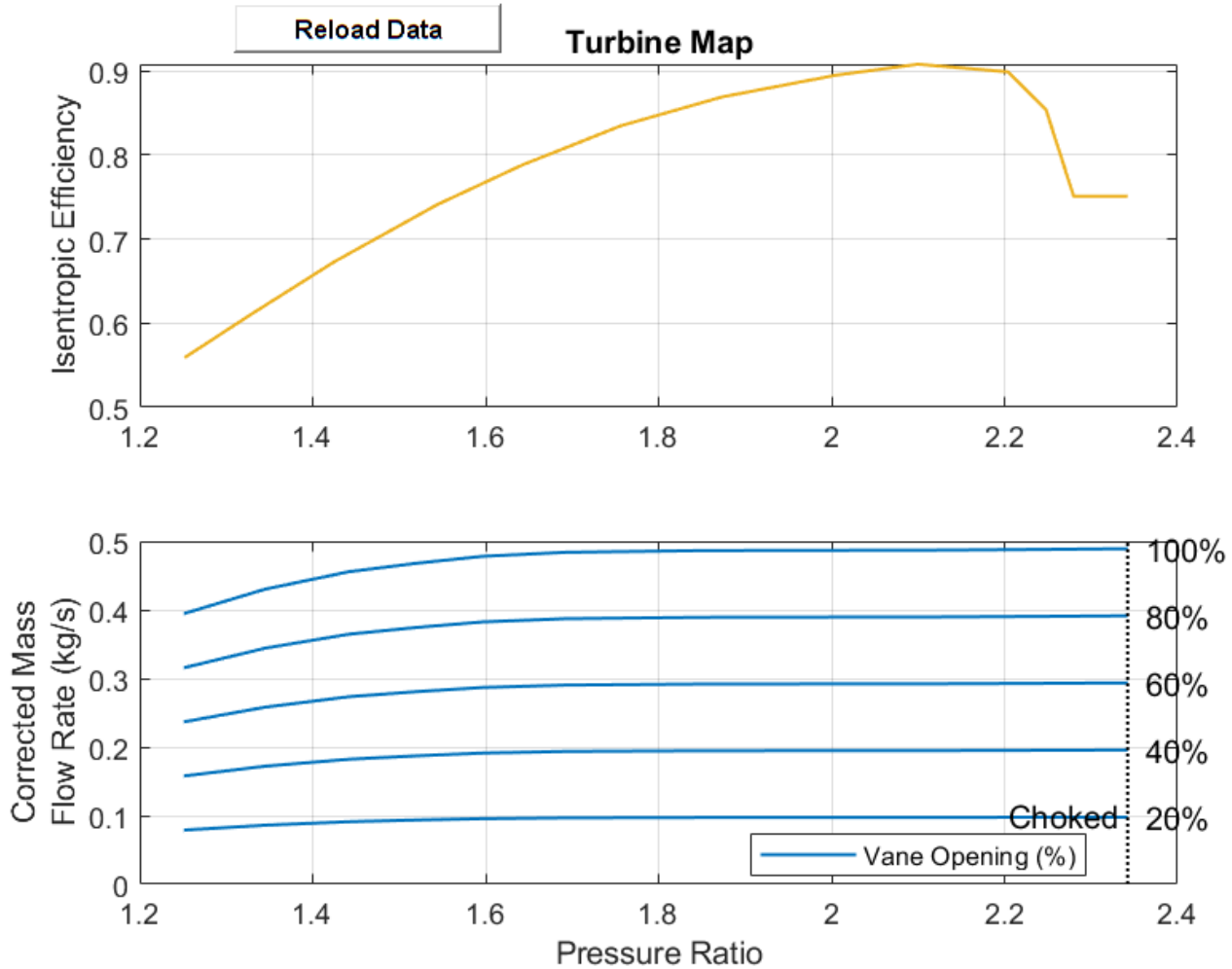


### Parameterization by Pressure Ratio

When **Turbine map parameterization** is Tabulated data - Flow rate and efficiency vs. pressure ratio, the turbine isentropic efficiency and mass flow rate are a function of the pressure ratio and do not account for any changes in the turbine rotational speed.

The last element of the **Corrected mass flow rate vector,  $\mathbf{mdot}(\mathbf{pr})$**  and the **Pressure ratio vector,  $\mathbf{pr}$**  parameters represents the corrected mass flow rate and pressure ratio at choked flow conditions.

This image shows the default turbine map when you use the 1-D parameterization.

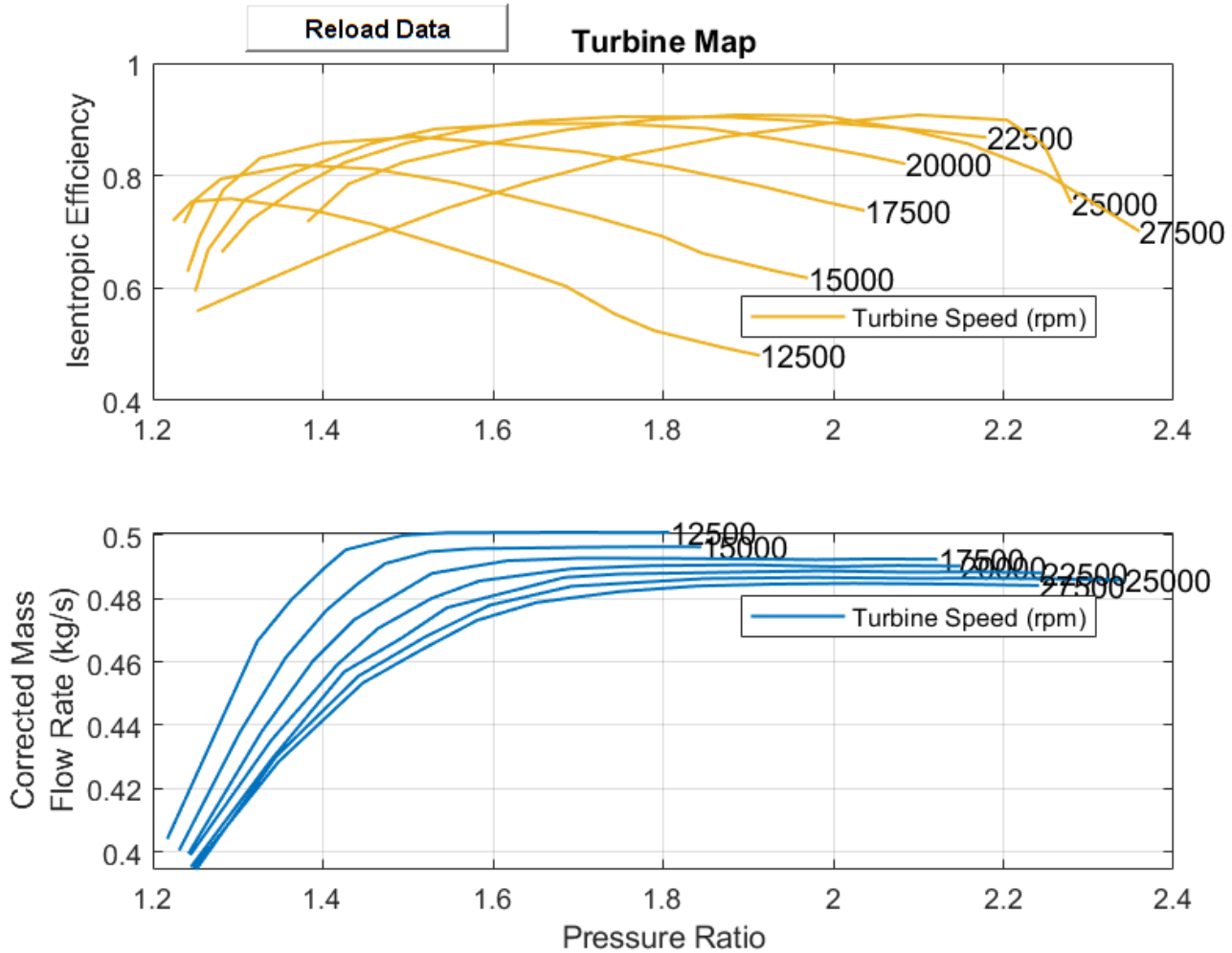


### Parameterization by Pressure Ratio and Corrected Mass Flow Rate

When **Turbine map parameterization** is set to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio, the turbine isentropic efficiency, pressure ratio, and corrected mass flow rate are a function of the corrected speed,  $N$ , and the map index,  $\beta$ . The block uses linear interpolation between data points for the efficiency, pressure ratio, and corrected mass flow rate parameters.

The last column of the **Corrected mass flow rate table,  $\dot{m}(N,\beta)$**  and the **Pressure ratio table,  $pr(N,\beta)$**  represent the corrected mass flow rate and pressure ratio at choked flow conditions.

This image shows the default turbine map when you use the 2-D parameterization.



### Continuity Equations

Mass is preserved over the block:

$$\dot{m}_A + \dot{m}_B = 0,$$

where  $\dot{m}_B$  is the mass flow rate at port **B**.

The block calculates the energy balance as

$$\Phi_A + \Phi_B - P_{fluid} = 0,$$

where:

- $\Phi_A$  is the energy flow rate at port **A**.
- $\Phi_B$  is the energy flow rate at port **B**.
- $P_{fluid}$  is the work done by the fluid, which the block determines from the change in total fluid specific enthalpy,  $P_{fluid} = \dot{m}_A \Delta h_{total}$ .

## Assumptions and Limitations

- The shaft does not rotate under reversed flow conditions. Results during reversed flows may not be accurate.

## Ports

### Input

#### **VN – Vane opening fraction, unitless**

physical signal

Vane opening fraction, specified as a unitless physical signal. The corrected mass flow rate scales linearly with the value of **VN**. A fraction of 1 corresponds to the tabulated data. The vane opening fraction does not influence the isentropic efficiency.

### Conserving

#### **A – Two-phase fluid inlet**

two-phase fluid

Two-phase fluid conserving port associated with the fluid entry port.

#### **B – Two-phase fluid outlet**

two-phase fluid

Two-phase fluid conserving port associated with the fluid exit port.

#### **C – Turbine case**

mechanical translational

Port associated with the turbine casing.

#### **R – Turbine shaft**

mechanical translational

Port associated with the turbine shaft torque and angular velocity.

## Parameters

### Parameterization

#### **Turbine map parameterization – Performance parameterization**

Analytical - Nominal pressure ratio and corrected mass flow rate (default) |  
 Tabulated data - Flow rate and efficiency vs. pressure ratio | Tabulated data -  
 Flow rate and efficiency vs. corrected speed and pressure ratio

Performance parameterization specification:

- Analytical - Nominal pressure ratio and corrected mass flow rate: Parameterize turbine isentropic efficiency and corrected mass flow rate analytically.
- Tabulated data - Flow rate and efficiency vs. pressure ratio: Parameterize turbine isentropic efficiency and corrected mass flow rate by pressure ratio.

- **Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio:** Parameterize turbine isentropic efficiency and corrected mass flow rate by corrected speed and pressure ratio.

**Minimum vane opening – Minimum opening fraction**

1e-3 (default) | positive scalar in the range (0,1]

Minimum vane opening fraction. This value is the lower boundary to the signal at **VN**. The block multiplies the value of this parameter by the mass flow rate to obtain the minimum corrected mass flow rate through the turbine.

**Maximum vane opening – Maximum opening fraction**

1 (default) | positive scalar in the range (0,1]

Maximum vane opening. This value is the upper boundary to the signal at **VN**. The block multiplies the value of this parameter by the mass flow rate to obtain the maximum corrected mass flow rate through the turbine.

**Report when fluid is not fully vapor – Fluid not fully vapor notification**

None (default) | Warning | Error

Whether the block does nothing, generates a warning, or generates an error when the block detects fluid that is not fully vapor.

**Corrected speed index vector, N – Tabulated data shaft speed indices**

250 .\* [50, 60, 70, 80, 90, 100, 110] rpm (default) | vector of positive scalars

Vector of constant shaft speeds for tabular parameterization of corrected mass flow rate and isentropic efficiency.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

**Flow Rate Data****Nominal pressure ratio – Pressure ratio value**

2 (default) | positive scalar

Pressure ratio value under nominal operating conditions for the analytical parameterization.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

**Nominal corrected mass flow rate – Corrected mass flow rate value**

0.48 kg/s (default) | positive scalar

Corrected mass flow rate value under nominal operating conditions for the analytical parameterization.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

**Pressure ratio vector, pr – Vector of pressure ratios**

[1.251, 1.345, 1.442, 1.521, 1.596, 1.692, 1.849, 1.972, 2.1, 2.173, 2.259, 2.3424] (default) | vector of positive scalars

Vector of pressure ratio values for the tabulated parameterization of corrected mass flow rate. This vector must have the same number of elements as the **Corrected mass flow rate vector, mdot(pr)** parameter and all elements must be greater than 1. The last element must be the pressure ratio at choked conditions.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

**Corrected mass flow rate vector, mdot(pr) – Vector of corrected mass flow rate values**

0.01.\*[39.439, 43.01, 45.556, 46.801, 47.792, 48.388, 48.634, 48.67, 48.689, 48.747, 48.825, 48.912] kg/s (default) | vector of positive scalars

Vector of corrected mass flow rate values for the tabulated parameterization of corrected mass flow rate. This vector must have the same number of elements as the **Pressure ratio vector, pr** parameter and all elements must be greater than 0. The last element must be the corrected mass flow rate at choked conditions.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

**Pressure ratio table, pr(N,beta) – Turbine map pressure ratio data**

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Corrected speed index vector, N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[1.217, 1.285, 1.323, 1.363, 1.402, 1.427, 1.495, 1.545, 1.6, 1.687, 1.747, 1.8074; 1.231, 1.302, 1.356, 1.404, 1.443, 1.473, 1.525, 1.577, 1.635, 1.709, 1.782, 1.845; 1.242, 1.328, 1.388, 1.437, 1.528, 1.617, 1.704, 1.811, 1.915, 1.979, 2.053, 2.1226; 1.244, 1.339, 1.417, 1.465, 1.528, 1.584, 1.692, 1.787, 1.899, 2, 2.075, 2.1492; 1.245, 1.34, 1.425, 1.492, 1.546, 1.684, 1.748, 1.882, 1.987, 2.084, 2.167, 2.2458; 1.251, 1.345, 1.442, 1.521, 1.596, 1.692, 1.849, 1.972, 2.1, 2.173, 2.259, 2.3424; 1.248, 1.348, 1.447, 1.516, 1.581, 1.651, 1.749, 1.839, 1.93, 2.024, 2.154, 2.242]

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

### Corrected mass flow rate table, $\dot{m}(N, \beta)$ — Turbine map corrected mass flow rate data

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of corrected mass flow rates at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Constant speed index vector**, **N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

0.01.\*[40.403, 44.417, 46.653, 47.966, 48.97, 49.544, 50.001, 50.081, 50.086, 50.095, 50.09, 50.0922; 40.044, 43.754, 46.125, 47.626, 48.513, 49.105, 49.481, 49.58, 49.597, 49.624, 49.638, 49.633; 39.941, 43.795, 46.017, 47.335, 48.795, 49.199, 49.279, 49.27, 49.248, 49.23, 49.255, 49.2428; 39.896, 43.512, 45.914, 47.061, 48.011, 48.558, 48.943, 49.042, 49.069, 49.01, 49.046, 49.0266; 39.524, 42.934, 45.686, 46.743, 47.715, 48.67, 48.777, 48.836, 48.876, 48.836, 48.845, 48.8184; 39.439, 43.01, 45.556, 46.801, 47.792, 48.388, 48.634, 48.67, 48.639, 48.647, 48.625, 48.5912; 39.502, 42.849, 45.336, 46.385, 47.312, 47.877, 48.222, 48.397, 48.459, 48.482, 48.455, 48.414] kg/s

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

#### Efficiency Data

##### Constant isentropic efficiency — Isentropic efficiency value

0.8 (default) | positive scalar

Isentropic efficiency under nominal operating conditions for the analytical parametrization.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Analytical - Nominal pressure ratio and corrected mass flow rate.

##### Pressure ratio vector, **pr** — Vector of pressure ratios

[1.252, 1.328, 1.425, 1.544, 1.642, 1.757, 1.873, 2.005, 2.1, 2.204, 2.248, 2.28] (default) | vector of positive scalars

Vector of pressure ratio values for the tabulated parameterization of isentropic efficiency. This vector must have the same number of elements as the **Isentropic efficiency vector,  $\eta(\mathbf{pr})$**  parameter and all elements must be greater than 1.

#### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.



**Isentropic efficiency vector, eta(pr) – Vector of isentropic efficiencies**

[.559, .61, .673, .741, .788, .835, .869, .895, .908, .899, .854, .751]  
(default) | vector of elements in the range (0,1]

Vector of isentropic efficiency values for the tabulated parameterization of isentropic efficiency. This vector must have the same number of elements as the **Pressure ratio vector, pr** parameter and all elements must be greater than 0 and less than or equal to 1.

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. pressure ratio.

**Pressure ratio table, pr(N,beta) – Turbine map pressure ratio data**

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine outlet-to-inlet pressure ratios at the specified corrected shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Constant speed index vector, N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[1.224, 1.246, 1.292, 1.387, 1.457, 1.534, 1.61, 1.686, 1.743, 1.79, 1.871, 1.914; 1.237, 1.25, 1.28, 1.369, 1.459, 1.553, 1.629, 1.716, 1.799, 1.846, 1.927, 1.97; 1.241, 1.255, 1.283, 1.326, 1.401, 1.509, 1.591, 1.704, 1.806, 1.913, 1.994, 2.037; 1.25, 1.265, 1.308, 1.364, 1.456, 1.532, 1.637, 1.739, 1.851, 1.934, 2.042, 2.085; 1.281, 1.314, 1.371, 1.425, 1.498, 1.574, 1.647, 1.749, 1.878, 1.979, 2.091, 2.18; 1.252, 1.328, 1.425, 1.544, 1.642, 1.757, 1.873, 2.005, 2.1, 2.204, 2.248, 2.28; 1.382, 1.43, 1.495, 1.586, 1.688, 1.791, 1.887, 1.99, 2.079, 2.158, 2.249, 2.217]

**Dependencies**

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

**Isentropic efficiency table, eta(N,beta) – Turbine map isentropic efficiency data**

*M*-by-*N* matrix (default)

*M*-by-*N* matrix of turbine isentropic efficiencies at the specified constant shaft speed and  $\beta$  value. The block employs linear interpolation between the table elements. *M* and *N* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Constant speed index vector, N** parameter.
- *N* is the number of  $\beta$  indices in the table.

The default table values are:

[.72, .754, .759, .739, .714, .679, .643, .603, .554, .524, .494, .48; .716, .757, .794, .819, .812, .788, .761, .728, .692, .662, .632, .618; .629, .691, .775, .831, .858, .869, .859, .842, .816, .782, .752, .738; .594, .668, .757, .804, .857, .883, .892, .893, .884, .865, .835, .821; .664, .72, .779, .823,

.858, .883, .897, .905, .904, .896, .883, .868; .559, .61, .673, .741, .788, .835, .869, .895, .908, .899, .854, .751; .718, .785, .824, .855, .882, .9, .908, .906, .884, .857, .804, .701]

### Dependencies

To enable this parameter, set **Turbine map parameterization** to Tabulated data - Flow rate and efficiency vs. corrected speed and pressure ratio.

### Reference Data

#### Reference pressure for corrected flow — Correcting pressure

0.101325 MPa (default) | positive scalar

Pressure at which the turbine data consolidates to a corrected trend line.

#### Reference temperature for corrected flow — Correcting temperature

373.15 K (default) | positive scalar

Temperature at which the turbine data consolidates to a corrected trend line.

#### Mechanical efficiency — Efficiency of conversion to torque

0.9 (default) | positive scalar in the range [0,1]

Efficiency of the conversion from reduction in specific enthalpy to shaft torque.

#### Inlet area at port A — Turbine inlet area

0.01 m<sup>2</sup> (default) | positive scalar

Turbine inlet cross-sectional area.

#### Outlet area at port B — Turbine outlet area

0.01 m<sup>2</sup> (default) | positive scalar

Turbine outlet cross-sectional area.

## Version History

Introduced in R2022b

## References

- [1] Kurzke, Joachim. "How to Get Component Maps for Aircraft Gas Turbine Performance Calculations." *Volume 5: Manufacturing Materials and Metallurgy; Ceramics; Structures and Dynamics; Controls, Diagnostics and Instrumentation; Education; General*, American Society of Mechanical Engineers, 1996, p. V005T16A001.
- [2] Plencner, Robert M. "Plotting component maps in the Navy/NASA Engine Program (NNEP): A method and its usage." *NASA Technical Memorandum*, 1989.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

Compressor (2P)

## Two-Phase Fluid Predefined Properties (2P)

Predefined working fluids for two-phase networks

**Library:** Simscape / Fluids / Two-Phase Fluid / Utilities



### Description

The Two-Phase Fluid Predefined Properties (2P) block sets the working fluid properties of your two-phase system. The available predefined fluids are:

- Water (R-718)
- R-134a
- R-1234yf
- R-404a
- R-410a
- R-407c
- R-22
- Ammonia (R-717)
- CO<sub>2</sub> (R-744)
- Isobutane (R-600a)

If you would like to specify your own working fluid properties, use the Foundation Library Two-Phase Fluid Properties (2P) block. If you do not specify a fluid, the system defaults will apply. See “Specify Fluid Properties” for more details.

### Fluid Properties Range

#### Water (R-718)

The fluid properties are provided for a pressure range of 0.001 to 95 MPa, and temperature range (at 1 atmosphere) of 273.16 to 1,245.8 K.

#### R-134a

The fluid properties are provided for a pressure range of 0.001 to 5.5 MPa, and temperature range (at 1 atmosphere) of 177.08 to 424.4 K.

#### R-1234yf

The fluid properties are provided for a pressure range of 0.04 to 3.2 MPa, and temperature range (at 1 atmosphere) of 223.52 to 387.45 K.

#### R-404a

The fluid properties are provided for a pressure range of 0.003 to 12 MPa, and temperature range (at 1 atmosphere) of 171.6 to 550.94 K.

**R-410a**

The fluid properties are provided for a pressure range of 0.001 to 6 MPa, and temperature range (at 1 atmosphere) of 146.19 to 427.25 K.

**R-407c**

The fluid properties are provided for a pressure range of 0.001 to 6 MPa, and temperature range (at 1 atmosphere) of 158.85 to 427.92 K.

**R-22**

The fluid properties are provided for a pressure range of 0.001 to 8 MPa, and temperature range (at 1 atmosphere) of 120.77 to 519.49 K.

**Ammonia (R-717)**

The fluid properties are provided for a pressure range of 0.008 to 95 MPa, and temperature range (at 1 atmosphere) of 195.5 to 543.9 K.

**CO<sub>2</sub> (R-744)**

The fluid properties are provided for a pressure range of 0.55 to 50 MPa, and temperature range (at 1 MPa) of 216.94 to 1,389.4 K. Note that the triple point of CO<sub>2</sub> is higher than atmospheric pressure, and therefore the minimum valid pressure is adjusted accordingly. When using CO<sub>2</sub> as the working fluid, ensure that connected blocks with initial pressure parameters, such as a Reservoir (2P) block, are equal to or greater this minimum pressure.

**Isobutane (R-600a)**

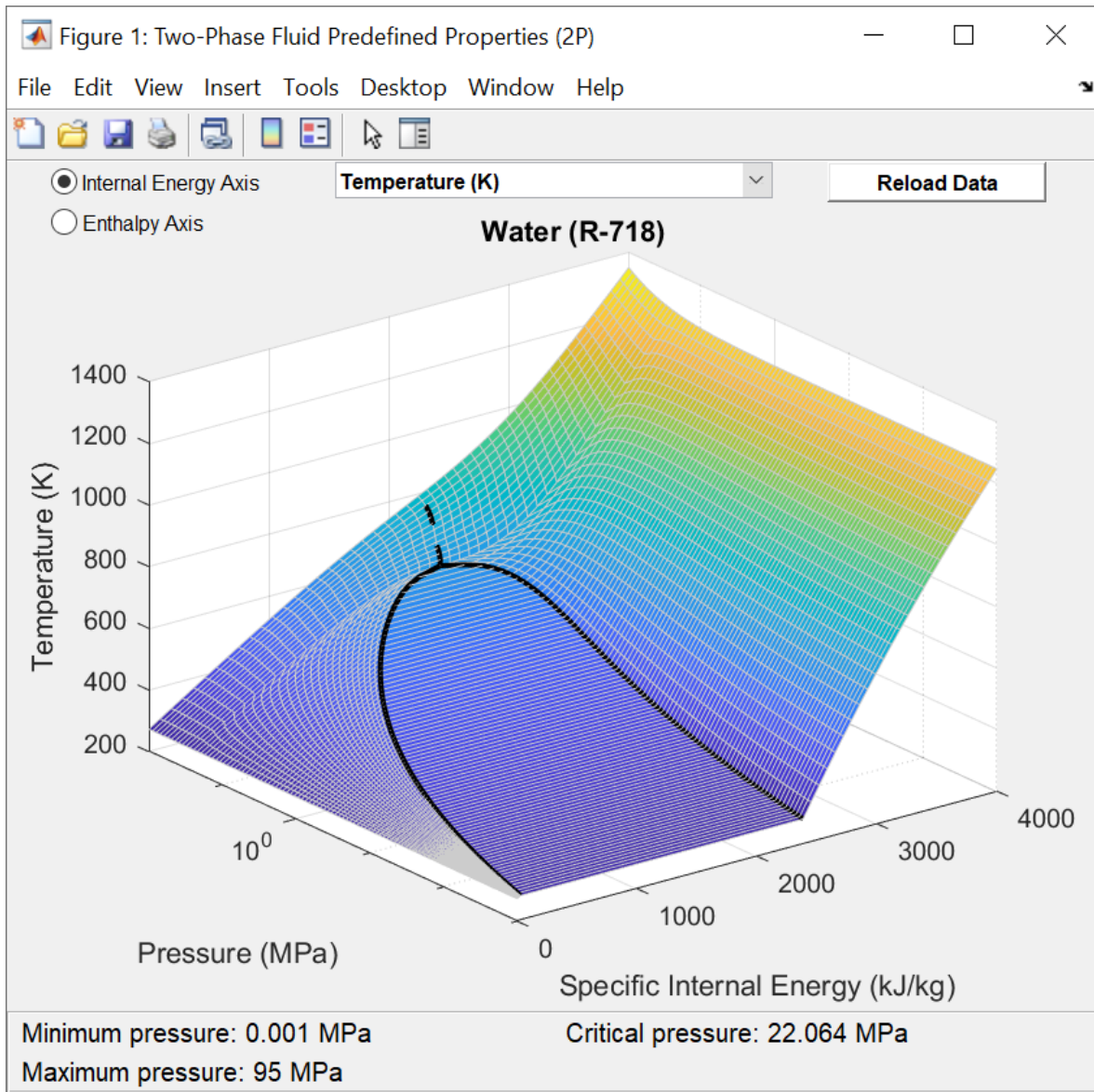
The fluid properties are provided for a pressure range of 0.0001 to 15 MPa, and temperature range (at 1 atmosphere) of 121.02 to 516.64 K.

**Visualizing Fluid Properties**

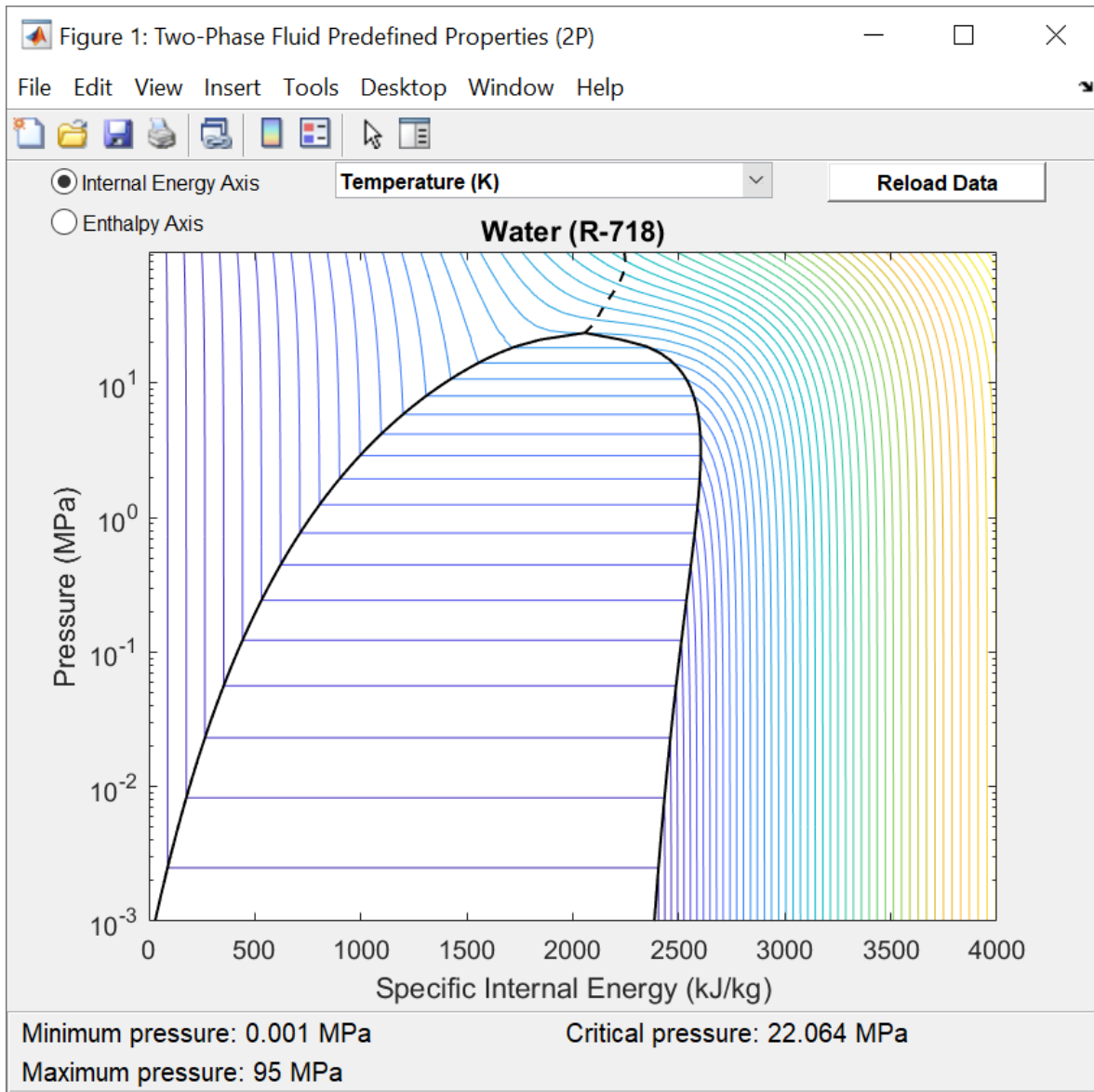
To visualize the:

- Specific volume
- Specific entropy
- Temperature
- Kinematic viscosity
- Thermal conductivity
- Prandtl number

of the network fluid as a function of specific internal energy or specific enthalpy and pressure, right-click on the block and select **Fluids > Plot Fluid Properties (3D)**:



or **Fluids > Plot Fluid Properties (Contours):**



Use the **Reload Data** button to regenerate the plot whenever the fluid selection or fluid parameters change.

## Ports

### Conserving

#### A — Connection port

two-phase fluid

Two-phase fluid conserving port that connects the block to the network. This port connects to any point on a two-phase connection line within a block diagram. When you connect the Two-Phase Fluid Predefined Properties (2P) block to a network line, the fluid properties are propagated to all blocks in the circuit.

## Parameters

### Two-phase fluid — Working fluid

Water (R-718) (default) | R-134a | R-1234yf | R-410a blend | R-404a blend | R-407c blend | R-22 | Ammonia (R-717) | CO<sub>2</sub> (R-744) | Isobutane (R-600a)

Predefined working fluid options.

### Atmospheric pressure — Environmental pressure

0.101325 MPa (default) | positive scalar

Environmental pressure of the system.

### Dynamic pressure threshold for flow reversal — Sets region in which numerical smoothing is applied

0.01 Pa (default) | positive scalar

Sets region in which numerical smoothing is applied. A transition region is defined around 0 MPa between the positive and negative values of the **Dynamic pressure threshold for flow reversal**. Within this transition region, the calculated properties are adjusted to ensure a smooth transition.

## Version History

Introduced in R2020b

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Two-Phase Fluid Properties (2P)



# Valve Actuator

Simplified model of valve driver



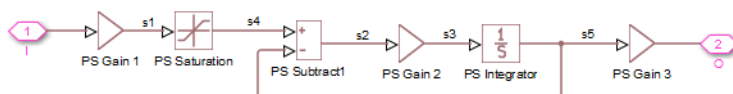
## Library

Valve Actuators

## Description

The Valve Actuator block represents a simplified model of a valve actuator, which is especially suitable for real-time and HIL (hardware-in-the-loop) simulation. Its functionality is similar to the 2-Position Valve Actuator and 3-Position Valve Actuator blocks, but its characterization requires fewer parameters because it is built of components that are practically linear.

The Valve Actuator block is built using the blocks from the Simscape Physical Signals library. Both the input and the output of the block are physical signals. The block diagram of the model is shown in the following figure.



The gain of the PS Gain 1 block establishes the steady-state relationship between the input and output signals. The PS Saturation block keeps the output signal within the +/- valve stroke range. The gain of the PS Gain 2 block is  $1/\text{Time constant}$ , which makes it possible to reproduce the first-order lag by combining this block with the PS Subtract and PS Integrator blocks.

The transfer function of the lag is

$$H(s) = \frac{1}{Ts + 1}$$

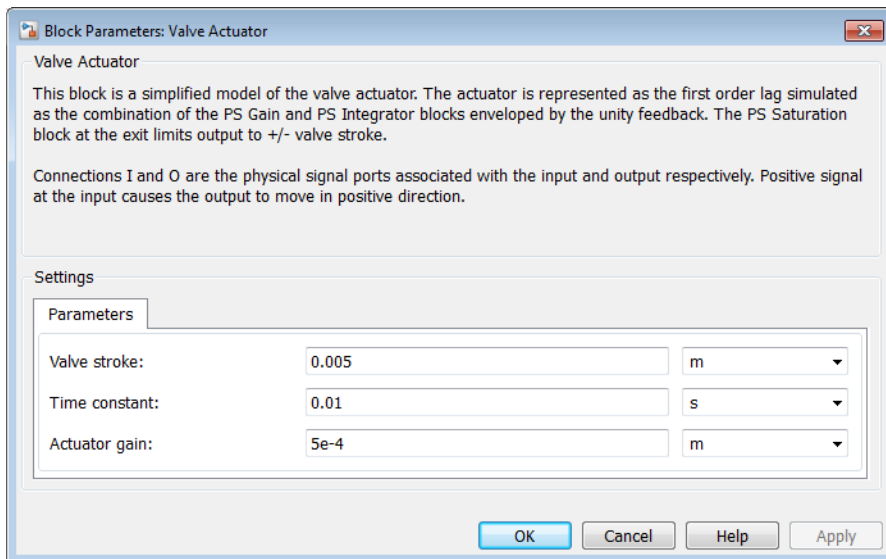
where  $T$  is the time constant. The gain of the PS Gain 3 block is set to 1.

---

**Note** This block is constructed out of blocks from the Simscape Physical Signals library (such as PS Add, PS Gain, and so on). Currently, the blocks in the Physical Signals library do not support unit propagation and checking. For more information, see “How to Work with Physical Units”.

---

## Dialog Box and Parameters



### Valve stroke

The desired valve stroke, which defines the saturation level of the PS Saturation block in the actuator model. The output of the actuator is kept within the +/- valve stroke range. The default value is 0.005 m.

### Time constant

Time constant of the first-order lag. The **Gain** parameter of the PS Gain 2 block is equal to 1/**Time constant**. The default value is 0.01 s.

### Actuator gain

Gain of the PS Gain 1 block in the block diagram of the actuator model. The default value is 5e-4 m.

## Ports

The block has one physical signal input port and one physical signal output port.

## Version History

Introduced in R2010a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

4-Way Ideal Valve | Proportional and Servo-Valve Actuator

# Valve Hydraulic Force

Axial hydraulic static force exerted on valve



## Library

Valve Forces

## Description

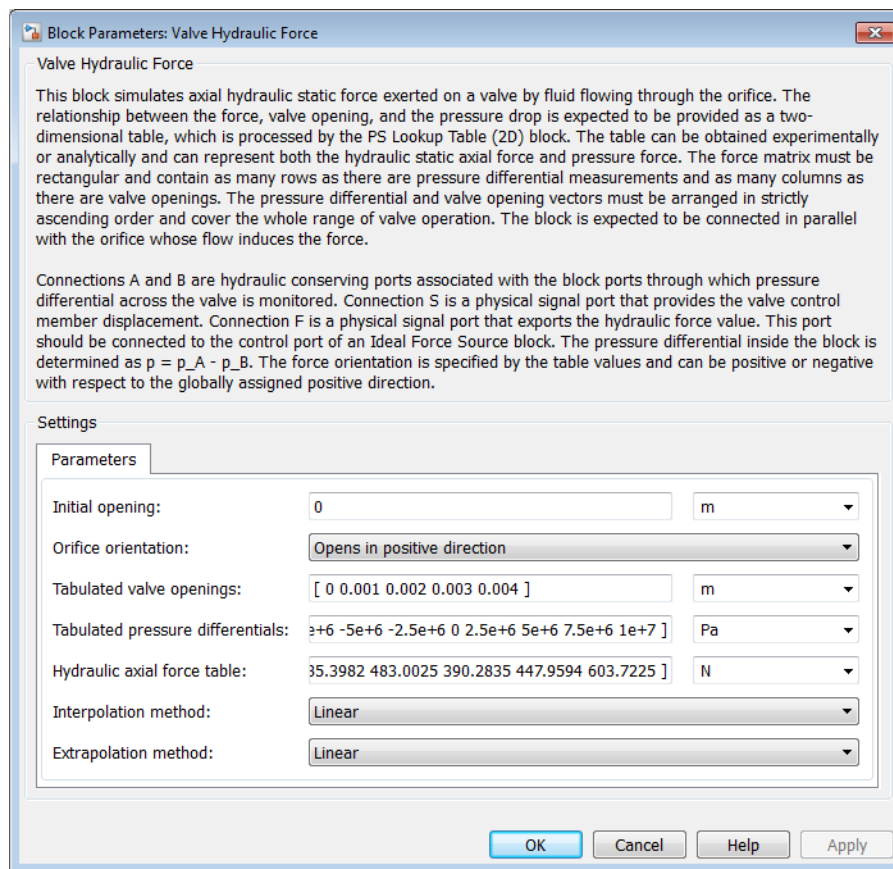
The Valve Hydraulic Force block simulates axial hydraulic static force exerted on a valve by fluid flowing through the orifice. The relationship between the valve opening, the pressure drop, and the force is provided as a two-dimensional table, which is processed by the PS Lookup Table (2D) block. The table can be obtained experimentally or analytically and can represent both the hydraulic static axial force and pressure forces. The force matrix must be rectangular and contain as many rows as there are pressure differential measurements and as many columns as there are valve openings. The pressure differential and opening vectors must be arranged in strictly ascending order and cover the whole range of valve operation. Connect the block in parallel with the orifice whose flow induces the force.

Connections A and B are hydraulic conserving ports that should be connected to the valve block ports in such a way as to monitor the pressure differential across the valve. Connection S is a physical signal port that provides the valve control member displacement. Connection F is a physical signal port that outputs the hydraulic axial force value. This port should be connected to the control port of an Ideal Force Source block. The pressure differential inside the block is determined as  $\Delta p = p_A - p_B$ . The force orientation is specified by the table values and can be positive or negative with respect to the globally assigned positive direction, depending on the value of the **Orifice orientation** parameter.

## Basic Assumptions and Limitations

No transient effects can be simulated.

## Dialog Box and Parameters



### Initial opening

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The default value is 0.

### Orifice orientation

The parameter is introduced to specify the effect of the valve opening on the valve force. The parameter can be set to one of two options: **Opens in positive direction** or **Opens in negative direction**. The value **Opens in positive direction** specifies an orifice that opens when the valve is shifted in the globally assigned positive direction. The default value is **Opens in positive direction**.

### Tabulated valve openings

Specify the vector of input values for valve openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are [ 0, 1e-3, 2e-3, 3e-3, 4e-3 ]. The **Tabulated valve openings** values will be used together with **Tabulated pressure differentials** for two-dimensional table lookup in the **Hydraulic axial force table**.

### Tabulated pressure differentials

Specify the vector of input values for pressure differentials as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of

values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are [-100e5, -75e5, -50e5, -25e5, 0, 25e5, 50e5, 75e5, 100e5].

### Hydraulic axial force table

Specify the hydraulic axial force as an m-by-n matrix, where m is the number of valve openings and n is the number of pressure differentials. Each value in the matrix specifies an axial force corresponding to a specific combination of valve opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in N, are:

```
[0, -127.3576, -27.8944, 227.2513, 575.3104; ...
0, -95.5182, -20.9208, 170.4385, 431.4828; ...
0, -63.6788, -13.9472, 113.6256, 287.6552; ...
0, -31.8394, -6.9736, 56.8128, 143.8276; ...
0, 0, 0, 0, 0; ...
196.3495, 120.7506, 97.5709, 111.9898, 150.9306; ...
392.6991, 241.5013, 195.1418, 223.9797, 301.8613; ...
589.0486, 362.2519, 292.7126, 335.9695, 452.7919; ...
785.3982, 483.0025, 390.2835, 447.9594, 603.7225]
```

### Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous surface with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (2D) block reference page.

### Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (2D) block reference page.

### Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Orifice orientation**
- **Interpolation method**
- **Extrapolation method**

All other block parameters are available for modification.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with a valve port.

B

Hydraulic conserving port associated with another valve port to monitor the pressure differential.

S

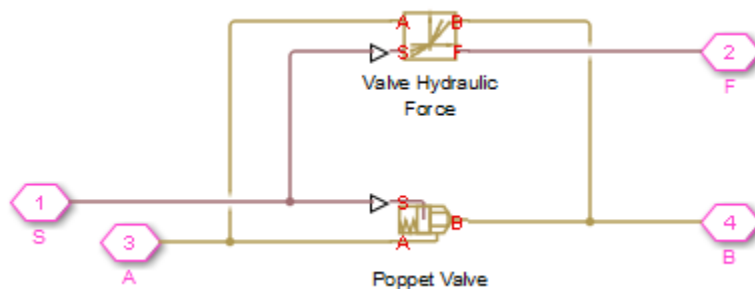
Physical signal port that provides the valve control member displacement.

F

Physical signal port that outputs hydraulic axial force.

## Examples

The following example shows a model of a poppet valve built of a Poppet Valve block and a Valve Hydraulic Force block. The Valve Hydraulic Force block is connected in parallel and provides tabulated data to compute hydraulic force acting on the valve. The force value is exported through the F port.



## Version History

Introduced in R2007a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Spool Orifice Hydraulic Force

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Valve Plate Orifice (IL)

Variable orifice in an isothermal axial-piston machine

**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors / Auxiliary Components



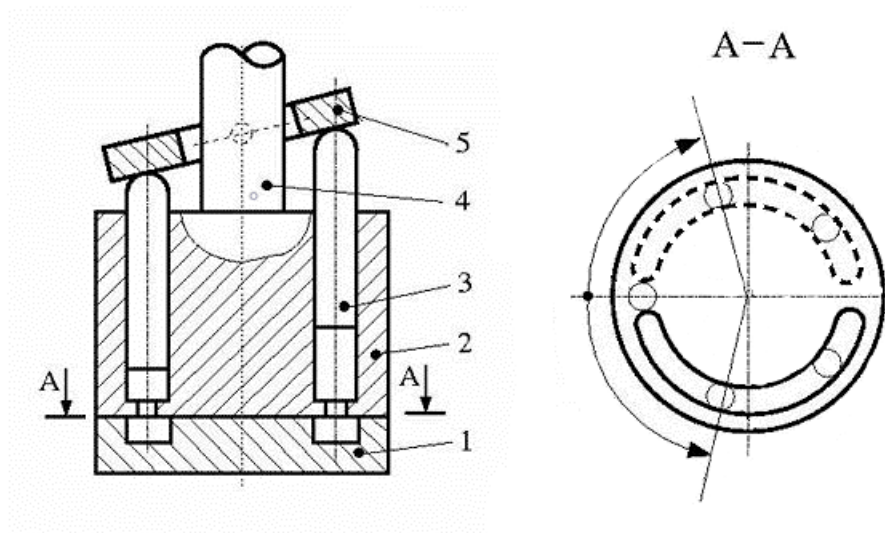
### Description

The Valve Plate Orifice (IL) block models a crescent-shaped opening between moving pistons and a pump in an axial-piston machine. The rotating pistons periodically connect to the pump intake or discharge through the orifice plate. You can connect two valve plate blocks to each cylinder of an axial-piston pump to represent both the pump inlet and outlet slots.

A rotating cylinder, with one crescent slot, is connected to the pump intake at port **A** and pump discharge at port **B**. These points are connected to the plate between the **Pressure carryover angle** and  $\pi$  radians (180 degrees) from each other. The plate rotation angle is set by the signal at port **G**. The cylinder position angle,  $\gamma$ , is the sum of the position signal,  $G$ , and the initial angle offset, the **Phase angle**,  $\gamma_0$ :

$$\gamma = \gamma_0 + G.$$

$\gamma$  is always between 0 and  $2\pi$ . For any combined signal and offset larger than  $2\pi$  rad,  $\gamma$  is maintained at  $2\pi$ , and for any combined signal and offset lower than 0 rad,  $\gamma$  is maintained at 0. To change the initial position of the orifice relative to the slot, you can adjust the **Phase angle** parameter.



### Axial-Piston Machine With Five Pistons

The numbers in the diagram indicate the components of an axial-piston machine:

- 1 Valve plate orifice
- 2 Rotor
- 3 Piston
- 4 Driving shaft
- 5 Swash plate

**Cylinder Angle**

The cylinder rotational alignment with the slot is described by the following angles:

- Cylinder angle at rotation onto slot,  $\gamma_1$ :

$$\gamma_1 = \Psi - \frac{r}{R}$$

- Cylinder angle at complete rotation onto slot,  $\gamma_2$ :

$$\gamma_2 = \Psi + \frac{r}{R}$$

- Cylinder angle at rotation beyond slot,  $\gamma_3$ :

$$\gamma_3 = \pi - 2\frac{r}{R}$$

- Cylinder angle at complete rotation beyond slot,  $\gamma_4$ :

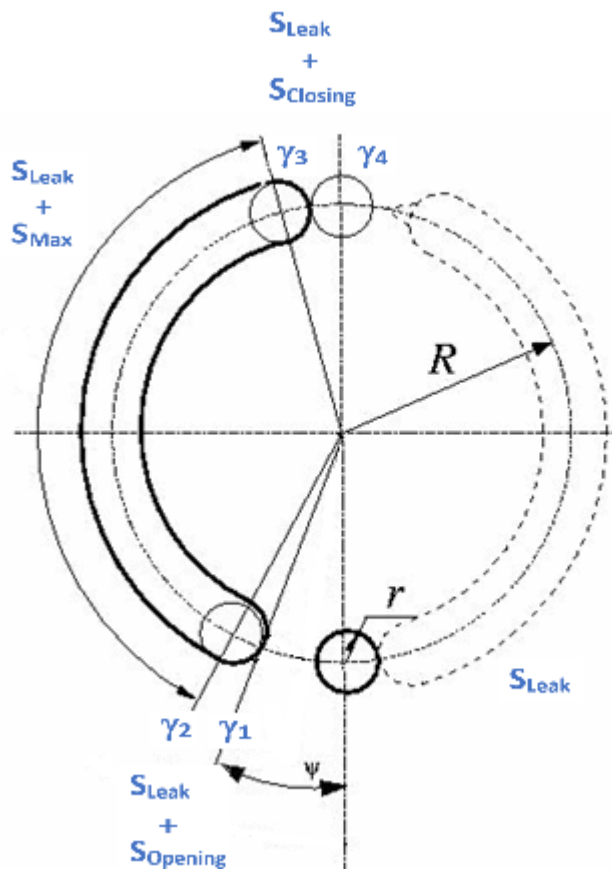
$$\gamma_4 = \pi$$

where:

- $\Psi$  is the **Pressure carryover angle**. This angle represents the average angular distance the piston travels during its pressure transition period from a closed to opened slot.
- $r$  is the half of the **Cylinder orifice diameter**.
- $R$  is the **Cylinder block pitch radius**.



## Orifice Opening Area



## Orifice area calculations during cylinder motion

The transition opening area, which is the opening between the cylinder rotation angles  $\gamma_1$  and  $\gamma_2$ , is calculated as:

$$A_{\gamma_1\gamma_2} = S_{opening} + S_{Leak} = r^2(2\beta_{opening} - \sin(2\beta_{opening})) + S_{Leak}.$$

The transition closing area, which is the opening between the cylinder rotation angles  $\gamma_3$  and  $\gamma_4$ , is calculated as:

$$A_{\gamma_3\gamma_4} = S_{closing} + S_{Leak} = r^2(2\beta_{closing} - \sin(2\beta_{closing})) + S_{Leak},$$

where the opening and closing parameters are:

$$\beta_{opening} = \cos^{-1}\left(\frac{R}{r}\sin\left(\frac{(\psi + \frac{r}{R}) - \gamma}{2}\right)\right),$$

and

$$\beta_{closing} = \cos^{-1}\left(\frac{R}{r}\sin\left(\frac{\gamma - (\pi - 2\frac{r}{R})}{2}\right)\right).$$

The area between  $\gamma_2$  and  $\gamma_3$  is  $A_{\gamma_2\gamma_3} = S_{Max} + S_{Leak}$ , and the area between  $\gamma_4$  and  $\gamma_1$  is  $A_{\gamma_4\gamma_1} = S_{Leak}$ . The maximum opening of the orifice is  $S_{Max} = \pi r^2$ .

A nonzero **Smoothing factor** can provide additional numerical stability when the orifice is in near-closed or near-open position.

### Numerically-Smoothed Orifice Angle

At the orifice slot entrance and exit angles, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to all calculated angles, but primarily influences the simulation at the extremes of this range.

The normalized transition opening angle is calculated as:

$$\widehat{\gamma}_{open} = \frac{\gamma}{(\gamma_2 - \gamma_1)}.$$

The **Smoothing factor**,  $s$ , is applied to the normalized angle:

$$\widehat{\gamma}_{open, smoothed} = \frac{1}{2} + \frac{1}{2} \sqrt{\widehat{\gamma}_{open}^2 + \left(\frac{s}{4}\right)^2} - \frac{1}{2} \sqrt{(\widehat{\gamma}_{open} - 1)^2 + \left(\frac{s}{4}\right)^2}.$$

The smoothed transition opening angle is:

$$\gamma_{open, smoothed} = \widehat{\gamma}_{open, smoothed} (\gamma_2 - \gamma_1).$$

Similarly, the normalized transition closing angle is:

$$\widehat{\gamma}_{close} = \frac{\gamma}{(\gamma_4 - \gamma_3)}.$$

The **Smoothing factor**,  $s$ , is applied to the normalized angle:

$$\widehat{\gamma}_{close, smoothed} = \frac{1}{2} + \frac{1}{2} \sqrt{\widehat{\gamma}_{close}^2 + \left(\frac{s}{4}\right)^2} - \frac{1}{2} \sqrt{(\widehat{\gamma}_{close} - 1)^2 + \left(\frac{s}{4}\right)^2}.$$

The smoothed transition closing angle is:

$$\gamma_{close, smoothed} = \widehat{\gamma}_{close, smoothed} (\gamma_4 - \gamma_3)$$

### Mass Flow Rate Equation

The flow through a valve plate orifice is calculated from the pressure-area relationship:

$$\dot{m} = C_d A_{orifice} \sqrt{2\bar{\rho}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{orifice}$  is the area open to flow.
- $\bar{\rho}$  is the average fluid density.
- $\Delta p$  is the pressure drop over the valve,  $P_A - P_B$ .

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , which is the point of transition between laminar and turbulent flow in the fluid:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{orifice}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Entry point to the orifice.

#### B – Liquid port

isothermal liquid

Exit point from the orifice.

### Input

#### G – Cylinder rotation angle, rad

physical signal

Cylinder rotation angle in radians, specified as a physical signal..

## Parameters

#### Cylinder block pitch radius – Cylinder pitch radius

0.05 m (default) | positive scalar

Pitch radius of the rotating cylinder.

#### Cylinder orifice diameter – Diameter of the cylinder slot

2.5e-3 m (default) | positive scalar

Diameter of the cylinder slot.

#### Pressure carryover angle – Pressure transition distance

0.06 rad (default) | scalar

Average angular distance the piston travels during the pressure transition period from a closed to opening slot.

#### Phase angle – Initial plate offset angle

0 rad (default) | scalar

Initial plate offset angle. The total angle between the plate and slot is the sum of the **Phase angle** and the **Pressure carryover angle**,  $\Psi$ .

#### Leakage area – Gap area when in fully closed position

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in a fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Discharge coefficient – Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number – Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Smoothing factor – Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Swash Plate

## Orifice (TL)

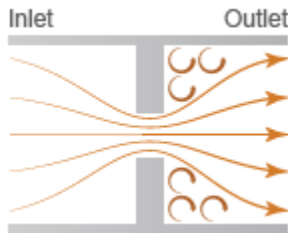
Constant-area or variable-area orifice in a thermal liquid system

**Library:** Simscape / Fluids / Thermal Liquid / Valves & Orifices



### Description

The Orifice (TL) block models the flow through a local restriction with a constant or variable opening area. For variable orifices, a control member connected to port **S** sets the opening position. The opening area is parametrized either linearly or by lookup table.



The block conserves mass such that

$$\dot{m}_A + \dot{m}_B = \rho v_A A_A + \rho v_B A_B = 0.$$

This mass balance implies that there is an increase in velocity when there is a decrease in area, and there is a reduction in velocity when the flow discharges into a larger area. In accordance with the Bernoulli principle, this change in velocity results in a region of lower pressure in the orifice and a higher pressure in the expansion zone. The resulting increase in pressure, which is called *pressure recovery*, depends on the discharge coefficient of the orifice and the ratio of the orifice and port areas.

### Constant Orifices

For constant orifices, the orifice area,  $A_{\text{orifice}}$ , does not change over the course of the simulation.

### Using the Constant Area Parameterization

The block calculates the mass flow rate as

$$\dot{m} = \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2\right)}} \sqrt{p_A - p_B} \approx \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2\right)}} \frac{p_A - p_B}{\left[(p_A - p_B)^2 + \Delta p_{\text{crit}}\right]^{1/4}},$$

where:

- $C_d$  is the **Discharge coefficient** parameter.
- $A_{\text{orifice}}$  is the instantaneous orifice open area.

- $A_{\text{port}}$  is the **Cross-sectional area at ports A and B** parameter.
- $\bar{\rho}$  is the average fluid density.

$PR_{\text{loss}}$  and  $\Delta p_{\text{crit}}$  are calculated in the same manner for constant and variable orifices.

This approximation for  $\dot{m}$  and the Local Resistance (TL) block are the same.

#### Using the Tabulated data - Volumetric flow rate vs. pressure drop Parameterization

The volumetric flow rate is determined from the tabular values of the pressure differential,  $\Delta p$ , which you can provide. If only non-negative values are provided for both the volumetric flow rate and pressure drop vectors, the table will be extrapolated to contain negative values. The volumetric flow rate is interpolated from this extended table.

#### Variable Orifices

For variable orifices, when you set **Opening orientation** to **Positive** control member displacement opens orifice opens the orifice when the signal at **S** is positive, while a **Negative** control member displacement opens orifice orientation opens the orifice when the signal at **S** is negative. In both cases, the signal is positive and the orifice opening is set by the magnitude of the signal.

#### Using the Linear - Area vs. control member position Parameterization

The orifice area  $A_{\text{orifice}}$  is based on the control member position and the ratio of orifice area and maximum control member position:

$$A_{\text{orifice}} = \frac{(A_{\text{max}} - A_{\text{leak}})}{\Delta S}(S - S_{\text{min}})\varepsilon + A_{\text{leak}},$$

where:

- $S_{\text{min}}$  is the **Control member position at closed orifice** parameter.
- $\Delta S$  is the **Control member travel between closed and open orifice** parameter.
- $A_{\text{max}}$  is the **Maximum orifice area** parameter.
- $A_{\text{leak}}$  is the **Leakage area** parameter.
- $\varepsilon$  is the **Opening orientation** parameter.

The volumetric flow rate is determined by the pressure-flow rate equation:

$$\dot{m} = \frac{C_d A_{\text{orifice}} \sqrt{2\bar{\rho}}}{\sqrt{PR_{\text{loss}} \left(1 - \left(\frac{A_{\text{orifice}}}{A}\right)^2\right) [\Delta p^2 + \Delta p_{\text{crit}}^2]^{1/4}} \Delta p$$

where  $A$  is the **Cross-sectional area at ports A and B**.

When the orifice is in a near-open or near-closed position in the linear parameterization, you can maintain numerical robustness in your simulation by adjusting the **Smoothing factor** parameter. If the **Smoothing factor** parameter is nonzero, the block smoothly saturates the opening area between  $A_{\text{leak}}$  and  $A_{\text{max}}$ . For more information, see "Numerical Smoothing".

#### Using the Tabulated data - Area vs. control member position Parameterization

When you use the Tabulated data - Area vs. control member position parameterization, the orifice area  $A_{\text{orifice}}$  is interpolated from the tabular values of opening area and the control member

position,  $\Delta S$ , which you can provide. As with the **Linear - Area vs. control member position** parameterization, the volumetric flow rate is determined by the pressure-flow rate equation:

$$\dot{m} = \frac{C_d A_{orifice} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left(1 - \left(\frac{A_{orifice}}{A}\right)^2\right)}} \frac{\Delta p}{[\Delta p^2 + \Delta p_{crit}^2]^{1/4}},$$

where  $A_{orifice}$  is:

- $A_{max}$ , the last element of the **Orifice area vector** parameter, if the physical signal at port **S** is larger than the last element of the **Control member position vector** parameter.
- $A_{leak}$ , the first element of the **Orifice area vector** parameter, if the physical signal at port **S** is smaller than the first element of the **Control member position vector** parameter.
- The linearly interpolated value of the **Orifice area vector** parameter if the calculated area is between the limits of the first and last element of the **Control member position vector** parameter.

$A_{orifice}$  is a function of the control member position received at port **S**. The block queries between data points with linear interpolation and uses nearest extrapolation for points beyond the table boundaries.

#### Using the Tabulated data - Volumetric flow rate vs. control member position and pressure drop Parameterization

The **Tabulated data - Volumetric flow rate vs. control member position and pressure drop** parameterization interpolates the volumetric flow rate directly from a user-provided volumetric flow rate table, which is based on the control member position and pressure drop over the orifice. The block queries between data points with linear interpolation and uses nearest extrapolation with respect to control member position and linear extrapolation with respect to pressure drop.

This data can include negative pressure drops and negative opening values. If a negative pressure drop is included in the dataset, the volumetric flow rate will change direction. However, the flow rate will remain unchanged for negative opening values.

#### Using the Tabulated data - Mass flow rate vs. control member position and pressure drop Parameterization

**Tabulated data - Mass flow rate vs. control member position and pressure drop** — Calculate the mass flow rate directly from the control member position and the pressure drop across the valve. The relationship between the three variables can be nonlinear and it is given by the tabulated data in the **Control member position vector, s**, **Pressure drop vector, dp**, and **Mass flow rate table, mdot(s,dp)** block parameters:

$$\dot{m}_{Tab} = \frac{\rho_{Avg}}{\rho_{Ref}} \dot{m}(\Delta S, \Delta p),$$

where  $\dot{m}$  is the tabulated form of the mass flow rate, a function of the control member position,  $h$ , and of the pressure drop across the orifice,  $\Delta p$ . The mass flow rate is adjusted for temperature and pressure by the ratio  $\rho_{Avg}/\rho_{Ref}$ , where  $\rho_{Avg}$  is the average fluid density in the orifice and  $\rho_{ref}$  is the reference density for the values of the **Reference inflow temperature** and **Reference inflow pressure** parameters.

## Pressure Loss

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area. The block calculates the pressure loss term,  $PR_{\text{loss}}$  as:

$$PR_{\text{loss}} = \frac{\sqrt{1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} - C_d \frac{A_{\text{orifice}}}{A_{\text{port}}}}{\sqrt{1 - \left(\frac{A_{\text{orifice}}}{A_{\text{port}}}\right)^2 (1 - C_d^2)} + C_d \frac{A_{\text{orifice}}}{A_{\text{port}}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{\text{loss}}$  is 1.

## Critical Pressure

The critical pressure difference,  $\Delta p_{\text{crit}}$ , is the pressure differential associated with the **Critical Reynolds number** parameter,  $Re_{\text{crit}}$ , which is the point of transition between laminar and turbulent flow in the fluid:

$$\Delta p_{\text{crit}} = \frac{\pi \bar{\rho}}{8 A_{\text{orifice}}} \left( \frac{\nu Re_{\text{crit}}}{C_d} \right)^2.$$

## Energy Balance

The block treats the orifice as an adiabatic component. No heat exchange can occur between the fluid and the wall that surrounds it. No work is done on or by the fluid as it traverses from inlet to outlet. With these assumptions, energy can flow by advection only, through ports **A** and **B**. By the principle of conservation of energy, the sum of the port energy flows must always equal zero:

$$\phi_A + \phi_B = 0,$$

where  $\phi$  is defined as the energy flow rate *into* the orifice through one of the ports (**A** or **B**).

## Ports

### Input

#### **S** – Control member displacement, m

physical signal

Instantaneous displacement of the valve control member.

### Conserving

#### **A** – Flow passage

thermal liquid

Thermal liquid conserving port associated with the opening through which the flow can enter or exit the valve.

#### **B** – Flow passage

thermal liquid



Thermal liquid conserving port associated with the opening through which the flow can enter or exit the valve.

## Parameters

### Orifice type — Type of orifice

Variable (default) | Constant

Type of orifice, defined by the orifice area. When set to **Variable**, the orifice area varies according to the input signal received at port **S**.

- **Orifice area**—The assigned area does not change over the simulation.
- **Tabulated data - Volumetric flow rate vs. pressure drop**—The area remains constant, but the volumetric flow rate through the orifice can vary. This value is interpolated directly from the **Volumetric flow rate vector** and the **Pressure drop vector** dataset.
- **Tabulated data - Mass flow rate vs. pressure drop**—The area remains constant, but the volumetric flow rate through the orifice can vary. This value is interpolated directly from the **Mass flow rate vector** and the **Pressure drop vector** dataset.

When you set **Orifice type** to **Variable**, there are four options.

- **Linear - Area vs. control member position**. Area is determined by a linear relationship to the control member position with respect to a fully open or fully closed orifice. The position is set by a varying physical signal at port **S**.
- **Tabulated data - Area vs. control member position**. The opening area is interpolated from the **Control member position vector** and the **Orifice area vector** based on the control member position received at port **S**.
- **Tabulated data - Volumetric flow rate vs. control member position and pressure drop**. The volumetric flow rate is directly interpolated from the user- provided **Control member position vector, s, Pressure drop vector, dp, and Volumetric flow rate table, q(s,dp)** parameters based on the control member position received at port **S** and the pressure drop across ports **A** and **B**.
- **Tabulated data - Mass flow rate vs. control member position and pressure drop**. The mass flow rate is directly interpolated from the user- provided **Control member position vector, s, Pressure drop vector, dp, and Mass flow rate table, mdot(s,dp)** parameters based on the control member position received at port **S** and the pressure drop across ports **A** and **B**.

### Orifice parameterization — Constant orifice parameterization

Orifice area (default) | Tabulated data - Volumetric flow rate vs. pressure drop |  
Tabulated data - Mass flow rate vs. pressure drop

Method by which to model the opening characteristics of the orifice. The default setting prescribes a linear relationship between the orifice opening area and the orifice opening. The alternative settings allow for a general, nonlinear relationship to be specified in tabulated form, in one case between the opening area and the orifice opening, in the other case between the mass flow rate and both the orifice opening and the pressure drop between the ports.

### Dependencies

To enable this parameter, set **Orifice type** to **Constant**.

**Orifice parameterization — Variable orifice parameterization**

Linear - Area vs. control member position (default) | Tabulated data - Area vs. control member position | Tabulated data - Volumetric flow rate vs. control member position and pressure drop | Tabulated data - Mass flow rate vs. control member position and pressure drop

When you set **Orifice type** to Variable, there are four options.

- **Linear - Area vs. control member position.** Area is determined by a linear relationship to the control member position with respect to a fully open or fully closed orifice. The position is set by a varying physical signal at port **S**.
- **Tabulated data - Area vs. control member position.** The opening area is interpolated from the **Control member position vector** and the **Orifice area vector** based on the control member position received at port **S**.
- **Tabulated data - Volumetric flow rate vs. control member position and pressure drop.** The volumetric flow rate is directly interpolated from the user- provided **Control member position vector, s, Pressure drop vector, dp, and Volumetric flow rate table, q(s,dp)** parameters based on the control member position received at port **S** and the pressure drop across ports **A** and **B**.
- **Tabulated data - Mass flow rate vs. control member position and pressure drop.** The mass flow rate is directly interpolated from the user- provided **Control member position vector, s, Pressure drop vector, dp, and Mass flow rate table, mdot(s,dp)** parameters based on the control member position received at port **S** and the pressure drop across ports **A** and **B**.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable.

**Orifice area — Area of orifice opening**

$1e-3 \text{ m}^2$  (default) | positive scalar

Cross-sectional area of the orifice opening.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Pressure drop vector — Vector of differential pressure values for tabular parameterization**

[-4, -3, -2, -1, -.5, 0, .5, 1, 2, 3, 4] MPa (default) | 1-by-*n* vector

Vector of pressure differential values for the tabular parameterization of volumetric flow rate. The values in this vector correspond one-to-one to values in the **Volumetric flow rate vector** parameter. The pressure drop vector values are listed in ascending order. The volumetric flow rate is interpolated directly from the **Volumetric flow rate vector** parameter, which depends on the **Pressure drop vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. pressure drop.

**Volumetric flow rate vector – Vector of volumetric flow rate values**

[-2.44, -2.12, -1.68, -1.22, -.84, 0, .85, 1.21, 1.7, 2.09, 2.41] .\* 1e-3  
m<sup>3</sup>/s (default) | 1-by-n vector

Vector of volumetric flow rate values for the tabular parameterization of volumetric flow rate. The values in this vector correspond one-to-one to values in the **Pressure drop vector** parameter. The volumetric flow rate is interpolated directly from the provided **Volumetric flow rate vector** parameter, which depends on the **Pressure drop vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. pressure drop.

**Mass flow rate vector – Vector of mass flow rate values**

[-2.44, -2.12, -1.68, -1.22, -.84, 0, .85, 1.21, 1.7, 2.09, 2.41] kg/s (default)  
| vector | 1-by-n vector

Vector of mass flow rate values for the tabular parameterization of volumetric flow rate. The values in this vector correspond one-to-one to values in the **Pressure drop vector** parameter. The mass flow rate is interpolated directly from the provided **Mass flow rate vector** parameter, which depends on the **Pressure drop vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Constant and **Orifice parameterization** to Tabulated data - Mass flow rate vs. pressure drop.

**Control member position at closed orifice – Control member offset**

0 m (default) | scalar

Initial control member offset when the variable orifice is fully closed.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and set **Orifice parameterization** to Linear – Area vs. control member position.

**Control member travel between closed and open orifice – Control member maximum stroke**

5e-3 m (default) | positive scalar

Maximum distance the control member travels between closed and open orifice. The orifice is fully open at the sum of the **Control member position at closed orifice** and **Control member travel between closed and open orifice** parameters.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

**Opening orientation – Direction of member movement that opens the orifice**

Positive control member displacement opens orifice (default) | Negative control member displacement opens orifice

Direction of member displacement that opens a variable orifice. A positive orientation means that a positive signal at **S** opens the orifice. A negative orientation means that a negative signal at **S** opens the orifice.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

**Maximum orifice area — Maximum orifice opening area**

1e-4 m<sup>2</sup> (default) | positive scalar

Maximum orifice area experienced during simulation. When using Tabulated data - Area vs. control member position, the maximum orifice area is the last element of the **Orifice area vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

**Leakage area — Orifice gap area when in fully closed position**

1e-10 m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in fully closed position. Any area smaller than this value is maintained at the specified leakage area. This parameter contributes to numerical stability by maintaining continuity in the flow.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

**Control member position vector — Vector of control member positions**

[0, .002, .004, .007, .017] m (default) | 1-by-n vector

Vector of control member positions for the tabular parameterization of orifice area. The vector elements correspond one-to-one to the values in the **Orifice area vector** parameter. The vector elements are listed in ascending order and the first element must be 0. The orifice opening area is interpolated from the **Orifice area vector**, which depends on the **Control member position vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Orifice area vector — Vector of orifice opening area values**

[1e-09, 2.0352e-07, 4.0736e-05, .00011438, .00034356] m<sup>2</sup> (default) | 1-by-n vector

Vector of orifice area values for the tabular parameterization of orifice area. The values in this vector correspond one-to-one with the elements in the **Control member position vector** parameter. The first element of this vector is the orifice leakage area and the last element is the maximum orifice area. The orifice opening area is interpolated from the **Orifice area vector** parameter, which depends on the **Control member position vector** parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Area vs. control member position.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the orifice is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Linear - Area vs. control member position.

**Pressure recovery — Whether to account for pressure increase in area expansions**

On (default) | Off

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area. This increase in pressure is not captured when **Pressure recovery** is set on Off.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.

- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

**Control member position vector,  $s$  – Vector of opening values**

[0, .002, .004, .007, .017] m (default) | 1-by- $n$  vector

Vector of control member positions for tabular parametrization of volumetric flow rate. The control member position vector forms an independent axis with the **Pressure drop vector,  $dp$**  parameter for the 2-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. A positive displacement corresponds to valve opening. The values are listed in ascending order and the first element must be 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop or Tabulated data - Mass flow rate vs. control member position and pressure drop.

**Pressure drop vector,  $dp$  – Vector of pressure drop values**

[.3, .5, .7] MPa (default) | 1-by- $n$  vector

Vector of pressure drop values for tabular parametrization of volumetric flow rate. The pressure drop vector forms an independent axis with the **Control member position vector,  $s$**  parameter for the 2-D dependent **Volumetric flow rate table,  $q(s,dp)$**  parameter. The values are listed in ascending order and must be greater than 0. Linear interpolation is employed between table data points.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop or Tabulated data - Mass flow rate vs. control member position and pressure drop.

**Volumetric flow rate table,  $q(s,dp)$  – Array of volumetric flow rate values**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] .\* 1e-3 m<sup>3</sup>/s (default) |  $M$ -by- $N$  matrix

$M$ -by- $N$  matrix of volumetric flow rates based on independent values of pressure drop and control member position.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Control member position vector,  $s$**  parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Volumetric flow rate vs. control member position and pressure drop.

**Mass flow rate table,  $\dot{m}(s, dp)$  — Array of mass flow rate values**

[1.7e-05, 2e-05, 2.6e-05; .0035, .0045, .0053; .7, .9, 1.06; 1.96, 2.5, 3; 6, 7.7, 9.13] kg/s (default) |  $M$ -by- $N$  matrix

Mass flow rates based on independent values of pressure drop and control member position.  $M$  and  $N$  are the sizes of the corresponding vectors:

- $M$  is the number of elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of elements in the **Control member position vector,  $s$**  parameter.

**Dependencies**

To enable this parameter, set **Orifice type** to Variable and **Orifice parameterization** to Tabulated data - Mass flow rate vs. control member position and pressure drop.

**Reference inflow temperature — Inlet temperature at which to specify the tabulated data**

293.15 K (default) | positive scalar in units of temperature

Nominal inlet temperature, with reference to absolute zero, at which to specify the tabulated data. This parameter is used to adjust the mass flow rate according to the temperature measured during simulation.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. opening and pressure drop.

**Reference inflow pressure — Inlet pressure at which to specify the tabulated data**

0.101325 MPa (default) | positive scalar in units of pressure

Nominal inlet pressure, with reference to absolute zero, at which to specify the tabulated data. This parameter is used to adjust the mass flow rate according to the pressure measured during simulation.

**Dependencies**

To enable this parameter, set **Orifice parameterization** to Tabulated data - Mass flow rate vs. opening and pressure drop.

**Cross-sectional area at ports A and B — Area at orifice entry or exit**

0.01 m<sup>2</sup> (default) | positive scalar

Cross-sectional area at the entry and exit ports **A** and **B**. This area is used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Dependencies**

To enable this parameter, set either:

- **Orifice type** to Variable and **Orifice parameterization** to either Linear - Area vs. control member position or Tabulated data - Area vs. control member position.
- **Orifice type** to Constant and **Orifice parameterization** to Orifice area.

## Version History

Introduced in R2022a

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**



# Variable Orifice

Generic hydraulic variable orifice



## Library

Orifices

## Description

The block represents a variable orifice of any type as a data-sheet-based model. Depending on data listed in the manufacturer's catalogs or data sheets for your particular orifice, you can choose one of the following model parameterization options:

- **By maximum area and opening** — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.
- **By area vs. opening table** — Use this option if the catalog or data sheet provides a table of the orifice passage area based on the control member displacement  $A=A(h)$ .
- **By pressure-flow characteristic** — Use this option if the catalog or data sheet provides a two-dimensional table of the pressure-flow characteristics  $q=q(p, h)$ .

In the first case, the passage area is assumed to be linearly dependent on the control member displacement, that is, the orifice is assumed to be closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. In the second case, the passage area is determined by one-dimensional interpolation from the table  $A=A(h)$ . In both cases, a small leakage area is assumed to exist even after the orifice is completely closed. Physically, it represents a possible clearance in the closed valve, but the main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. An isolated or “hanging” part of the system could affect computational efficiency and even cause failure of computation.

In the first and second cases, the flow rate is computed according to the following equations:

$$q = C_D \cdot A(h) \sqrt{\frac{2}{\rho} \frac{\Delta p}{(\Delta p^2 + p_{Cr}^2)^{1/4}}}$$

$$\Delta p = p_A - p_B,$$

$$h = x_0 + x \cdot or$$

For the first parameterization, the opening area ( $A$ ) is a piecewise function of the control member position ( $h$ ). The area saturates at its leakage value when the control member is in the fully closed position ( $h_{min}$ ). It saturates at its maximum value when the control member is in the fully open position ( $h_{max}$ ).

$$A(h) = \begin{cases} A_{\text{leak}} & h \leq h_{\text{min}} \\ \frac{A_{\text{max}}}{h_{\text{max}}}h, & h > 0 \\ A_{\text{max}}, & h \geq h_{\text{max}} \end{cases}$$

The minimum control member position is calculated as:

$$h_{\text{min}} = \frac{h_{\text{max}}}{A_{\text{max}}}A_{\text{leak}}$$

For the second parameterization, the opening area is a tabulated function of control member displacement. As with the linear parameterization, the area saturates at its leakage value when the control member is in the fully closed position, and it saturates at its maximum value when the control member is in the fully open position. Between the closed and open positions:

$$A = f(h)$$

The table summarizes the parameters used in the equations.

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$C_D$	Flow discharge coefficient
$A(h)$	Instantaneous orifice passage area
$A_{\text{max}}$	Orifice maximum area
$h_{\text{max}}$	Control member maximum displacement
$x_0$	Initial opening
$x$	Control member displacement from initial position
$h$	Orifice opening
$or$	Orifice orientation indicator. The variable assumes +1 value if the control member displacement in the globally assigned positive direction opens the orifice, and -1 if positive motion decreases the opening.
$\rho$	Fluid density
$A_{\text{leak}}$	Closed orifice leakage area
$p_{\text{cr}}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{\text{cr}}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = (p_{\text{avg}} + p_{\text{atm}})(1 - B_{\text{lam}})$$

$$p_{\text{avg}} = (p_A + p_B)/2$$

where

$p_{\text{avg}}$	Average pressure between the block terminals
$p_{\text{atm}}$	Atmospheric pressure, 101325 Pa
$B_{\text{lam}}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{cr} = \frac{\rho}{2} \left( \frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

$D_H$	Instantaneous orifice hydraulic diameter
$\nu$	Fluid kinematic viscosity
$Re_{cr}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

In the third case, when an orifice is defined by its pressure-flow characteristics, the flow rate is determined by two-dimensional interpolation. In this case, neither flow regime nor leakage flow rate is taken into account, because these features are assumed to be introduced through the tabulated data. Pressure-flow characteristics are specified with three data sets: array of orifice openings, array of pressure differentials across the orifice, and matrix of flow rate values. Each value of a flow rate corresponds to a specific combination of an opening and pressure differential.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as  $\Delta p = p_A - p_B$ . Positive signal at the physical signal port S opens or closes the orifice depending on the value of the orifice orientation indicator.

## Variables

To set the priority and initial target values for the block variables prior to simulation, use the **Initial Targets** section in the block dialog box or Property Inspector. For more information, see “Set Priority and Initial Target for Block Variables”.

Nominal values provide a way to specify the expected magnitude of a variable in a model. Using system scaling based on nominal values increases the simulation robustness. Nominal values can come from different sources, one of which is the **Nominal Values** section in the block dialog box or Property Inspector. For more information, see “Modify Nominal Values for a Block Variable”.

## Basic Assumptions and Limitations

- Fluid inertia is not taken into account.
- For orifices specified by pressure-flow characteristics (the third parameterization option), the model does not explicitly account for the flow regime or leakage flow rate, because the tabulated data is assumed to account for these characteristics.

## Parameters

### Model parameterization

Select one of the following methods for specifying the orifice:

- **By maximum area and opening** — Provide values for the maximum orifice area and the maximum orifice opening. The passage area is linearly dependent on the control member displacement, that is, the orifice is closed at the initial position of the control member (zero displacement), and the maximum opening takes place at the maximum displacement. This is the default method.
- **By area vs. opening table** — Provide tabulated data of orifice openings and corresponding orifice areas. The passage area is determined by one-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.
- **By pressure-flow characteristic** — Provide tabulated data of orifice openings, pressure differentials, and corresponding flow rates. The flow rate is determined by two-dimensional table lookup. You have a choice of two interpolation methods and two extrapolation methods.

### Orifice maximum area

Specify the area of a fully opened orifice. The parameter value must be greater than zero. The default value is  $5e-5 \text{ m}^2$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Orifice maximum opening

Specify the maximum displacement of the control member. The parameter value must be greater than zero. The default value is  $5e-4 \text{ m}$ . This parameter is used if **Model parameterization** is set to **By maximum area and opening**.

### Orifice opening vector, **s**

Specify the vector of input values for orifice openings as a one-dimensional array. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in meters, are  $[-0.002 \ 0 \ 0.002 \ 0.005 \ 0.015]$ . If **Model parameterization** is set to **By area vs. opening table**, the **Tabulated orifice openings** values will be used together with **Tabulated orifice area** values for one-dimensional table lookup. If **Model parameterization** is set to **By pressure-flow characteristic**, the **Tabulated orifice openings** values will be used together with **Tabulated pressure differentials** and **Tabulated flow rates** for two-dimensional table lookup.

### Orifice area vector

Specify the vector of orifice areas as a one-dimensional array. The vector must be of the same size as the orifice openings vector. All the values must be positive. The default values, in  $\text{m}^2$ , are  $[1e-09 \ 2.0352e-07 \ 4.0736e-05 \ 0.00011438 \ 0.00034356]$ . This parameter is used if **Model parameterization** is set to **By area vs. opening table**.

### Pressure differential vector, **dp**

Specify the pressure differential vector as a one-dimensional array. The vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values, in Pa, are  $[-1e+07 \ -5e+06 \ -2e+06 \ 2e+06 \ 5e+06 \ 1e+07]$ . This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

**Volumetric flow rate table,  $q(s,dp)$** 

Specify the flow rates as an  $m$ -by- $n$  matrix, where  $m$  is the number of orifice openings and  $n$  is the number of pressure differentials. Each value in the matrix specifies flow rate taking place at a specific combination of orifice opening and pressure differential. The matrix size must match the dimensions defined by the input vectors. The default values, in  $m^3/s$ , are:

```
[-1e-07 -7.0711e-08 -4.4721e-08 4.4721e-08 7.0711e-08 1e-07;
-2.0352e-05 -1.4391e-05 -9.1017e-06 9.1017e-06 1.4391e-05 2.0352e-05;
-0.0040736 -0.0028805 -0.0018218 0.0018218 0.0028805 0.0040736;
-0.011438 -0.0080879 -0.0051152 0.0051152 0.0080879 0.011438;
-0.034356 -0.024293 -0.015364 0.015364 0.024293 0.034356;]
```

This parameter is used if **Model parameterization** is set to **By pressure-flow characteristic**.

**Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve (**By area vs. opening table**) or surface (**By pressure-flow characteristic**) with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

**Extrapolation method**

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve or surface with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the PS Lookup Table (1D) and PS Lookup Table (2D) block reference pages.

**Orifice orientation**

The parameter is introduced to specify the effect of the orifice control member motion on the valve opening. The parameter can be set to one of two options: **Opens in positive direction** or **Opens in negative direction**. The value **Opens in positive direction** specifies an orifice whose control member opens the valve when it is shifted in the globally assigned positive direction. The parameter is extremely useful for building a multi-orifice valve with all the orifices being controlled by the same spool. The default value is **Opens in positive direction**.

**Flow discharge coefficient**

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Initial opening**

Orifice initial opening. The parameter can be positive (underlapped orifice), negative (overlapped orifice), or equal to zero for zero lap configuration. The value of initial opening does not depend on the orifice orientation. The default value is 0.

### **Leakage area**

The total area of possible leaks in the completely closed orifice. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

### **Laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

### **Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

### **Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

### **Restricted Parameters**

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Model parameterization**
- **Orifice orientation**
- **Interpolation method**
- **Extrapolation method**
- **Laminar transition specification**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Model parameterization** parameter at the time the model entered Restricted mode.

### **Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

## Ports

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

S

Physical signal port to control spool displacement.

The flow rate is positive if fluid flows from port A to port B. Positive signal at the physical signal port S opens or closes the orifice depending on the value of the parameter **Orifice orientation**.

## Examples

The “Hydraulic Flapper-Nozzle Amplifier” example illustrates the use of the Variable Orifice block in hydraulic systems.

## Version History

**Introduced in R2006a**

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Annular Orifice | Constant Area Hydraulic Orifice | Fixed Orifice | Orifice with Variable Area Round Holes | Orifice with Variable Area Slot | PS Lookup Table (1D) | PS Lookup Table (2D) | Variable Area Hydraulic Orifice

## Topics

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Variable Orifice Between Round Holes

Hydraulic variable orifice at intersection of two holes

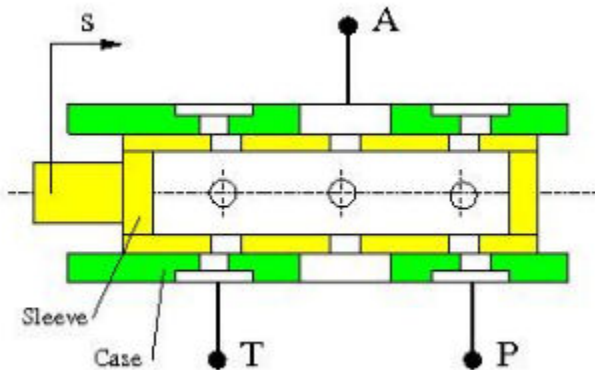


### Library

Orifices

### Description

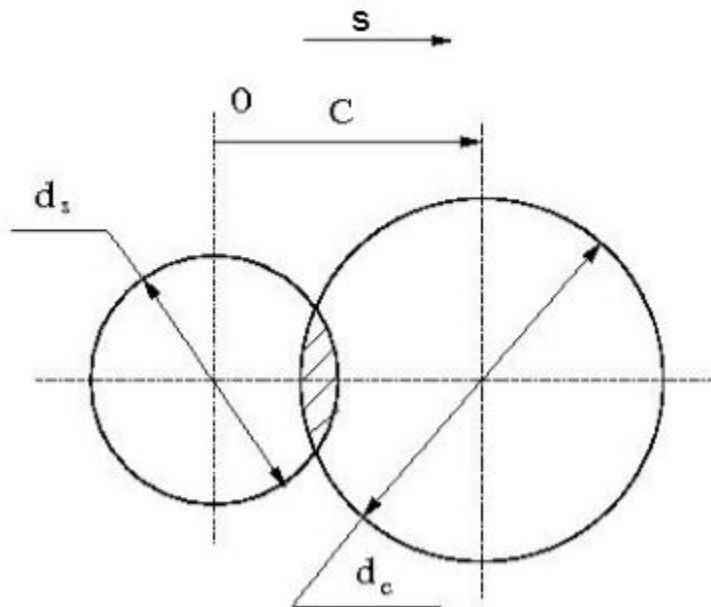
The Variable Orifice Between Round Holes block models a variable orifice created by two interacting round holes. These holes can have different diameters. One hole is located in the sleeve, while the other is drilled in the case, with the sleeve sliding along the case. Such a configuration is frequently seen in cartridge valves, as shown in this 3-way valve schematic.



The block can contain multiple identical interacting pairs of holes. The following schematic shows the calculation diagram for one such pair of round holes, where

$s$	Sleeve displacement from initial position
$c$	Distance between hole centers
$d_s$	Sleeve hole diameter
$d_c$	Case hole diameter





The flow rate through the orifice is proportional to the orifice area and to the pressure differential across the orifice, according to these equations:

$$A = \begin{cases} A_{leak} & \text{for } c \geq (r + R) \\ A_{leak} + r^2 \cdot a \cos\left(\frac{c^2 + r^2 - R^2}{2cr}\right) + R^2 \cdot a \cos\left(\frac{c^2 - r^2 + R^2}{2cr}\right) & \text{for } c < (r + R) \\ -\frac{1}{2}\sqrt{(-c + r + R)(c + R - r)(c + r - R)(c + r + R)} & \end{cases}$$

$$q = z \cdot C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$\Delta p = p_A - p_B,$$

where

$q$	Flow rate
$p$	Pressure differential
$p_A, p_B$	Gauge pressures at the block terminals
$A$	Instantaneous passage area between orifices
$c$	Instantaneous distance between hole centers
$r$	Smaller hole radius
$R$	Larger hole radius
$z$	Number of hole pairs
$C_D$	Flow discharge coefficient

$\rho$	Fluid density
$A_{\text{leak}}$	Closed orifice leakage area
$p_{\text{cr}}$	Minimum pressure for turbulent flow

The minimum pressure for turbulent flow,  $p_{\text{cr}}$ , is calculated according to the laminar transition specification method:

- By pressure ratio — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = (p_{\text{avg}} + p_{\text{atm}})(1 - B_{\text{lam}})$$

$$p_{\text{avg}} = (p_A + p_B)/2$$

where

$p_{\text{avg}}$	Average pressure between the block terminals
$p_{\text{atm}}$	Atmospheric pressure, 101325 Pa
$B_{\text{lam}}$	Pressure ratio at the transition between laminar and turbulent regimes ( <b>Laminar flow pressure ratio</b> parameter value)

- By Reynolds number — The transition from laminar to turbulent regime is defined by the following equations:

$$p_{\text{cr}} = \frac{\pi}{4A} \left( \frac{\text{Re}_{\text{cr}}}{C_D} \right)^2 \cdot \rho \cdot \frac{\nu^2}{2}$$

where

$\nu$	Fluid kinematic viscosity
$\text{Re}_{\text{cr}}$	Critical Reynolds number ( <b>Critical Reynolds number</b> parameter value)

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B. Positive signal at port S moves the sleeve in the positive direction.

## Basic Assumptions and Limitations

Inertial effects are not taken into account.

## Parameters

### Sleeve hole diameter

Diameter of the holes drilled in the sleeve. The default value is 0.005 m.

### Case hole diameter

Diameter of the holes drilled in the case. The default value is 0.0054 m.

### Number of interacting pairs

Number of interacting hole pairs. The default value is 1.

**Flow discharge coefficient**

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 0.7.

**Laminar transition specification**

Select how the block transitions between the laminar and turbulent regimes:

- **Pressure ratio** — The transition from laminar to turbulent regime is smooth and depends on the value of the **Laminar flow pressure ratio** parameter. This method provides better simulation robustness.
- **Reynolds number** — The transition from laminar to turbulent regime is assumed to take place when the Reynolds number reaches the value specified by the **Critical Reynolds number** parameter.

**Laminar flow pressure ratio**

Pressure ratio at which the flow transitions between laminar and turbulent regimes. The default value is 0.999. This parameter is visible only if the **Laminar transition specification** parameter is set to **Pressure ratio**.

**Critical Reynolds number**

The maximum Reynolds number for laminar flow. The value of the parameter depends on the orifice geometrical profile. You can find recommendations on the parameter value in hydraulics textbooks. The default value is 12. This parameter is visible only if the **Laminar transition specification** parameter is set to **Reynolds number**.

**Leakage area**

The total area of possible leaks in the completely closed orifice. The main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the orifice is completely closed. The parameter value must be greater than 0. The default value is  $1e-12 \text{ m}^2$ .

**Global Parameters**

Parameters determined by the type of working fluid:

- **Fluid density**
- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

S

Physical signal port that provides the instantaneous value of the distance between the hole centers.

## **Version History**

**Introduced in R2014b**

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

[Annular Orifice](#) | [Orifice with Variable Area Round Holes](#) | [Orifice with Variable Area Slot](#) | [Variable Area Hydraulic Orifice](#) | [Variable Orifice](#)

### **Topics**

[“Upgrading Simscape Fluids Models Containing Hydraulics \(Isothermal\) Blocks”](#)

## Variable Overlapping Orifice (IL)

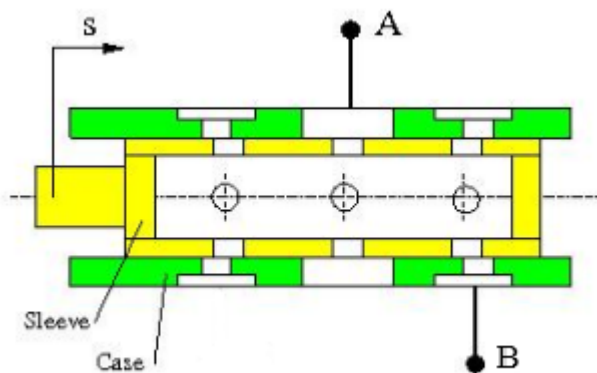
Orifice created by open segments with variable overlap in an isothermal system

**Library:** Simscape / Fluids / Isothermal Liquid / Valves & Orifices / Orifices



### Description

The Variable Overlapping Orifice (IL) block models flow through round holes with varying overlapping areas, such as a moving sleeve within a fixed case. The overlapping holes can have different diameters, but additional holes along the spool or sleeve have the same diameter.



### Overlapping Area

The flow rate depends on the variable open area created by overlapping holes in the sleeve and casing. This instantaneous opening area is calculated as:

$$A_{overlap} = r^2 \left[ \cos^{-1} \left( \frac{C^2 + r^2 - R^2}{2Cr} \right) - \left( \frac{C^2 + r^2 - R^2}{2Cr} \right) \sqrt{1 - \left( \frac{C^2 + r^2 - R^2}{2Cr} \right)^2} \right] \\ + R^2 \left[ \cos^{-1} \left( \frac{C^2 - r^2 + R^2}{2CR} \right) - \left( \frac{C^2 - r^2 + R^2}{2CR} \right) \sqrt{1 - \left( \frac{C^2 - r^2 + R^2}{2CR} \right)^2} \right],$$

where:

- $r$  is the diameter of the smaller hole.
- $R$  is the diameter of the larger hole.
- $C$  is the absolute distance between the hole centers, calculated from the physical signal at port **S**, the instantaneous sleeve position, and the **Sleeve position when holes are concentric**,  $S_0$ :  
 $C = |S - S_0|$ .

If the holes on the sleeve and casing have the same diameter, the overlap area becomes:

$$A_{overlap} = 2r^2 \left[ \cos^{-1} \left( \frac{C}{2r} \right) - \left( \frac{C}{2r} \right) \sqrt{1 - \left( \frac{C}{2r} \right)^2} \right].$$

You can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor** at the nearest and farthest points between hole centers. The block applies a smoothing function to the normalized hole center distance,

$$\widehat{C} = \frac{(C - R + r)}{(2r)}.$$

The function smoothly saturates the normalized hole center distance between 0 and 1.

For more information, see “Numerical Smoothing”

### Mass Flow Rate Equation

The flow through an orifice pair is calculated from the pressure-area relationship:

$$\dot{m} = \frac{C_d A_{orifice} \sqrt{2\bar{\rho}}}{\sqrt{PR_{loss} \left( 1 - \left( \frac{A_{orifice}}{A_{port}} \right)^2 \right) [\Delta p^2 + \Delta p_{crit}^2]^{1/4}} \Delta p,$$

where:

- $C_d$  is the **Discharge coefficient**.
- $A_{orifice}$  is the area open to flow,  $A_{orifice} = A_{overlap} + A_{leak}$ .
- $A$  is the **Cross-sectional area at ports A and B**.
- $\bar{\rho}$  is the average fluid density.

*Pressure loss* describes the reduction of pressure in the valve due to a decrease in area. The pressure loss term,  $PR_{loss}$  is calculated as:

$$PR_{loss} = \frac{\sqrt{1 - \left( \frac{A_{overlapping}}{A_{port}} \right)^2} (1 - C_d^2) - C_d \frac{A_{overlapping}}{A_{port}}}{\sqrt{1 - \left( \frac{A_{overlapping}}{A_{port}} \right)^2} (1 - C_d^2) + C_d \frac{A_{overlapping}}{A_{port}}}.$$

*Pressure recovery* describes the positive pressure change in the valve due to an increase in area. If you do not wish to capture this increase in pressure, set **Pressure recovery** to Off. In this case,  $PR_{loss}$  is 1.

The critical pressure difference,  $\Delta p_{crit}$ , is the pressure differential associated with the **Critical Reynolds number**,  $Re_{crit}$ , the flow regime transition point between laminar and turbulent flow:

$$\Delta p_{crit} = \frac{\pi \bar{\rho}}{8 A_{overlapping}} \left( \frac{\nu Re_{crit}}{C_d} \right)^2.$$

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Entry or exit point to the orifice.

#### B – Liquid port

isothermal liquid

Entry or exit point to the orifice.

### Input

#### S – Sleeve displacement, m

physical signal

Sleeve position with respect to the case, in m.

## Parameters

#### Sleeve hole diameter – Sleeve hole diameter

$5e-3$  m (default) | positive scalar

Diameter of the hole in the moving element.

#### Case hole diameter – Case hole diameter

$5.5e-3$  m (default) | positive scalar

Diameter of hole in the fixed element.

#### Sleeve position when holes are concentric – Moving element position when hole centers are aligned

$0$  m (default) | scalar

Moving element position when hole centers are aligned. This parameter is used to determine instantaneous overlap of the moving and stationary holes during simulation by comparison with the signal received at port S.

#### Number of interacting pairs – Number of overlapping orifices, in pairs

$1$  (default) | positive scalar

Number of overlapping orifices, in pairs. The sleeve-case pairs do not need to be aligned in the physical hardware being modeled.

#### Leakage area – Gap area when in fully closed position

$1e-10$  m<sup>2</sup> (default) | positive scalar

Sum of all gaps when the valve is in the fully closed position. Any area smaller than this value is maintained at the specified leakage area. This contributes to numerical stability by maintaining continuity in the flow.

**Cross-sectional area at ports A and B — Orifice area at conserving ports**

inf m<sup>2</sup> (default) | positive scalar

Areas at the entry and exit ports **A** and **B**, which are used in the pressure-flow rate equation that determines the mass flow rate through the orifice.

**Discharge coefficient — Discharge coefficient**

0.64 (default) | positive scalar

Correction factor that accounts for discharge losses in theoretical flows.

**Critical Reynolds number — Upper Reynolds number limit for laminar flow**

150 (default) | positive scalar

Upper Reynolds number limit for laminar flow through the orifice.

**Smoothing factor — Numerical smoothing factor**

0.01 (default) | positive scalar in the range [0,1]

Continuous smoothing factor that introduces a layer of gradual change to the flow response when the valve is in near-open or near-closed positions. Set this value to a nonzero value less than one to increase the stability of your simulation in these regimes.

**Pressure recovery — Whether to account for pressure increase in area expansions**

Off (default) | On

Whether to account for pressure increase when fluid flows from a region of smaller cross-sectional area to a region of larger cross-sectional area.

## Version History

Introduced in R2020a

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Spool Orifice (IL) | Annular Leakage (IL) | Orifice (IL)



# Variable-Displacement Motor

Variable-displacement bidirectional hydraulic motor

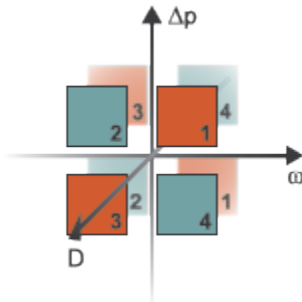
**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Variable-Displacement Motor block represents a device that extracts power from a hydraulic (isothermal liquid) network and delivers it to a mechanical rotational network. The motor displacement varies in proportion to the physical signal input specified at port C or D. The exact port used depends on the block variant selected. See “Ports” on page 1-1962.

Ports **A** and **B** represent the motor inlet and outlet, respectively. Port **S** represents the motor drive shaft. During normal operation, the angular velocity at port **S** is positive if the pressure drop from port **A** to port **B** is positive also. This operation mode is referred to here as forward motor.



## Operation Modes

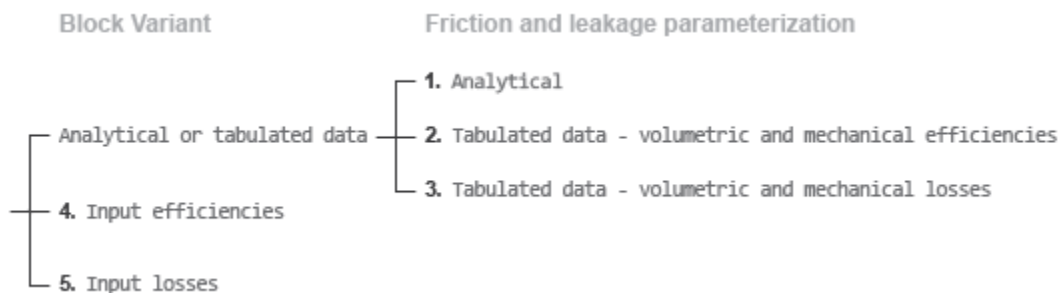
A total of four operation modes are possible. The working mode depends on the pressure drop from port **A** to port **B** ( $\Delta p$ ), on the angular velocity at port **S** ( $\omega$ ), and on the instantaneous volumetric displacement of the component ( $D$ ). The “Operation Modes” on page 1-1955 figure maps the modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart. The modes are labeled 1-4:

- Mode **1**: forward motor — A positive pressure drop generates a positive shaft angular velocity.
- Mode **2**: reverse pump — A negative shaft angular velocity generates a negative pressure gain (shown in the figure as a positive pressure drop).
- Mode **3**: reverse motor — A negative pressure drop generates a negative shaft angular velocity.
- Mode **4**: forward pump — A positive shaft angular velocity generates a positive pressure gain (shown in the figure as a negative pressure drop).

The response time of the motor is considered negligible in comparison with the system response time. The motor is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.

### Block Variants and Loss Parameterizations

The motor model accounts for power losses due to leakage and friction. Leakage is internal and occurs between the motor inlet and outlet only. The block computes the leakage flow rate and friction torque using your choice of five loss parameterizations. You select a parameterization using block variants and, in the **Analytical** or **tabulated data** case, the **Leakage and friction parameterization** parameter.



### Loss Parameterizations

The block provides three Simscape variants to select from. To change the active block variant, use the **Modeling option** parameter. The available variants are:

- **Analytical or tabulated data** — Obtain the mechanical and volumetric efficiencies or losses from analytical models based on nominal parameters or from tabulated data. Use the **Leakage and friction parameterization** parameter to select the exact input type.
- **Input efficiencies** — Provide the mechanical and volumetric efficiencies directly through physical signal input ports.
- **Input losses** — Provide the mechanical and volumetric losses directly through physical signal input ports. The mechanical loss is defined as the internal friction torque. The volumetric loss is defined as the internal leakage flow rate.

### Displacement Parameterizations

The displacement volume input depends on the block variant selected. If the active block variant is **Input efficiencies** or **Input losses**, the block obtains the instantaneous displacement volume directly from the physical signal input at port D.

If the active block variant is **Analytical or tabulated data**, the block computes the instantaneous displacement volume from the control member position specified at port C. This computation depends on the **Displacement parameterization** parameter setting:

- **Maximum displacement and control member stroke** — Compute the displacement volume per unit rotation as a linear function of the control member position specified at port C.
- **Displacement vs. control member position table** — Compute the displacement volume per unit volume using interpolation or extrapolation of displacement tabular data specified at discrete control member positions.

### Flow Rate and Driving Torque

The volumetric flow rate generated at the motor is

$$q = q_{\text{Ideal}} + q_{\text{Leak}},$$

where:

- $q$  is the net volumetric flow rate.
- $q_{\text{Ideal}}$  is the ideal volumetric flow rate.
- $q_{\text{Leak}}$  is the internal leakage volumetric flow rate.

The torque generated at the motor is

$$\tau = \tau_{\text{Ideal}} - \tau_{\text{Friction}},$$

where:

- $\tau$  is the net torque.
- $\tau_{\text{Ideal}}$  is the ideal torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal volumetric flow rate is

$$q_{\text{Ideal}} = D_{\text{Sat}} \cdot \omega,$$

and the ideal generated torque is

$$\tau_{\text{Ideal}} = D_{\text{Sat}} \cdot \Delta p,$$

where:

- $D_{\text{Sat}}$  is a smoothed displacement computed so as to remove numerical discontinuities between negative and positive displacements.
- $\omega$  is the instantaneous angular velocity of the rotary shaft.
- $\Delta p$  is the instantaneous pressure drop from inlet to outlet.

### Saturation Displacement

The saturation displacement depends on the block variant selected. If the active variant is Analytical or tabulated data,

$$D_{\text{Sat}} = \begin{cases} \text{sign}(D) \cdot D_{\text{Max}}, & |D| \geq D_{\text{Max}} \\ \sqrt{D^2 + D_{\text{Threshold}}^2}, & D \geq 0 \\ -\sqrt{D^2 + D_{\text{Threshold}}^2}, & D < 0 \end{cases},$$

where:

- $D$  is the instantaneous fluid displacement determined from the physical signal input specified at port **C** or port **D**.

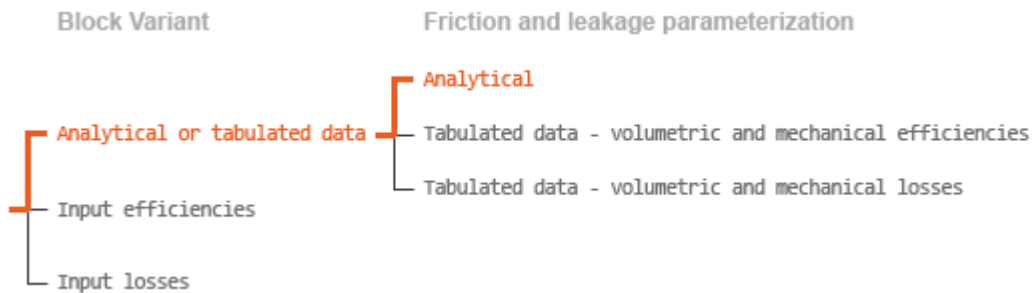
- $D_{Max}$  is the specified value of the **Maximum displacement** block parameter.
- $D_{Threshold}$  is the specified value of the **Displacement threshold for motor-pump transition** block parameter.

If the active variant is `Input efficiencies` or `Input losses`, there is no upper bound on the displacement input and the saturation displacement reduces to:

$$D_{Sat} = \begin{cases} \sqrt{D^2 + D_{Threshold}^2}, & D \geq 0 \\ -\sqrt{D^2 + D_{Threshold}^2}, & D < 0 \end{cases}$$

### Leakage Flow Rate and Friction Torque

The internal leakage flow rate and friction torque calculations depend on the block variant selected. If the block variant is `Analytical` or `tabulated data`, the calculations depend also on the **Leakage and friction parameterization** parameter setting. There are five possible permutations of block variant and parameterization settings.



### Case 1: Analytical Efficiency Calculation

If the active block variant is `Analytical` or `tabulated data` and the **Leakage and friction parameterization** parameter is set to `Analytical`, the leakage flow rate is

$$q_{Leak} = K_{HP}\Delta p,$$

and the friction torque is

$$\tau_{Friction} = \left( \tau_0 + K_{TP} \left| \frac{D_{Sat}}{D_{Max}} \right| |\Delta p| \right) \tanh\left( \frac{4\omega}{\omega_{Thresh}} \right),$$

where:

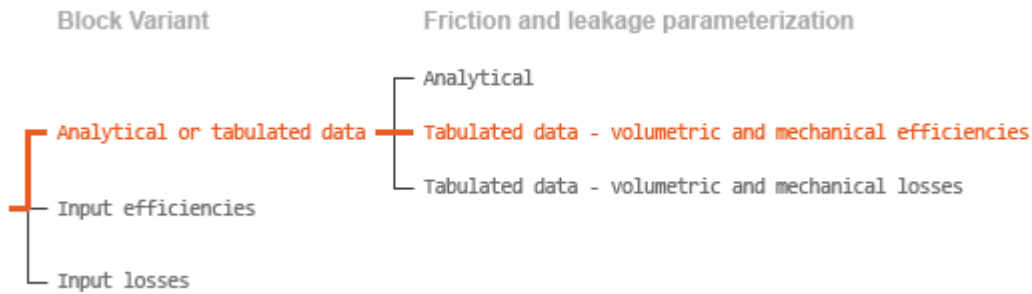
- $K_{HP}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.
- $K_{TP}$  is the specified value of the **Friction torque vs pressure drop coefficient** block parameter.
- $\tau_0$  is the specified value of the **No-load torque** block parameter.
- $\omega_{Threshold}$  is the threshold angular velocity for the motor-pump transition. The threshold angular velocity is an internally set fraction of the specified value of the **Nominal shaft angular velocity** block parameter.

The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{HP} = \frac{\nu_{Nom} \rho_{Nom} \omega_{Nom} D_{Max}}{\rho \nu} \frac{\Delta p_{Nom}}{\Delta p_{Nom}} \left( \frac{1}{\eta_{v,Nom}} - 1 \right),$$

where:

- $\nu_{Nom}$  is the **Nominal kinematic viscosity** parameter. This is the kinematic viscosity at which the nominal volumetric efficiency is specified.
- $\rho_{Nom}$  is the **Nominal fluid density** parameter. This is the density at which the nominal volumetric efficiency is specified.
- $\rho$  is the actual fluid density in the attached hydraulic (isothermal liquid) network. This density can differ from the **Nominal fluid density** parameter.
- $\omega_{Nom}$  is the **Nominal shaft angular velocity** parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.
- $\nu$  is the fluid kinematic viscosity in the attached hydraulic fluid network.
- $\Delta p_{Nom}$  is the **Nominal pressure drop** parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.
- $\eta_{v,Nom}$  is the **Volumetric efficiency at nominal conditions** parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.



## Case 2: Efficiency Tabulated Data

If the active block variant is **Analytical or tabulated data** and the **Leakage and friction parameterization** parameter is set to **Tabulated data – volumetric and mechanical efficiencies**, the leakage flow rate is

$$q_{Leak} = q_{Leak, Motor} \frac{(1 + \alpha)}{2} + q_{Leak, Pump} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{Friction} = \tau_{Friction, Motor} \frac{1 + \alpha}{2} + \tau_{Friction, Pump} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $q_{Leak, Motor}$  is the leakage flow rate in motor mode.
- $q_{Leak, Pump}$  is the leakage flow rate in pump mode.
- $\tau_{Friction, Pump}$  is the friction torque in pump mode.

- $\tau_{\text{Friction, Motor}}$  is the friction torque in motor mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4D}{D_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure drop threshold for motor-pump transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.
- $D_{\text{Threshold}}$  is the specified value of the **Displacement threshold for motor-pump transition** block parameter.

The leakage flow rate is computed from efficiency tabulated data through the equation

$$q_{\text{Leak, Motor}} = (1 - \eta_v)q,$$

in motor mode and through the equation

$$q_{\text{Leak, Pump}} = -(1 - \eta_v)q_{\text{Ideal}}.$$

in pump mode, where:

- $\eta_v$  is the volumetric efficiency obtained through interpolation or extrapolation of the **Volumetric efficiency table, e\_v(dp,w,D)** parameter data.

Similarly, the friction torque is computed from efficiency tabulated data through the equation

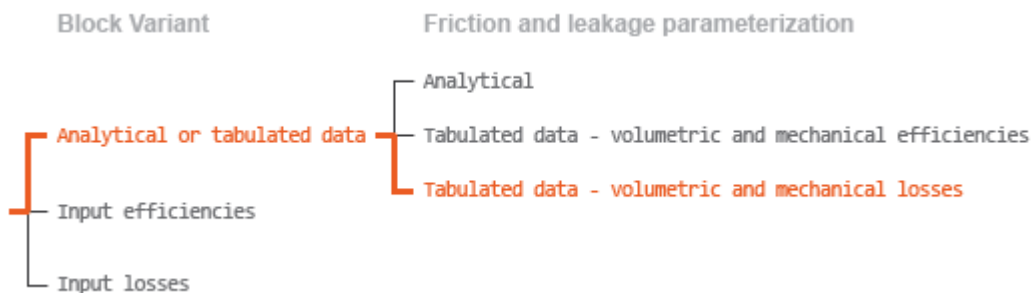
$$\tau_{\text{Friction, Motor}} = (1 - \eta_m)\tau_{\text{Ideal}},$$

in motor mode and through the equation

$$\tau_{\text{Friction, Pump}} = -(1 - \eta_m)\tau.$$

in pump mode, where:

- $\eta_m$  is the mechanical efficiency obtained through interpolation or extrapolation of the **Mechanical efficiency table, e\_m(dp,w,D)** parameter data.



### Case 3: Loss Tabulated Data

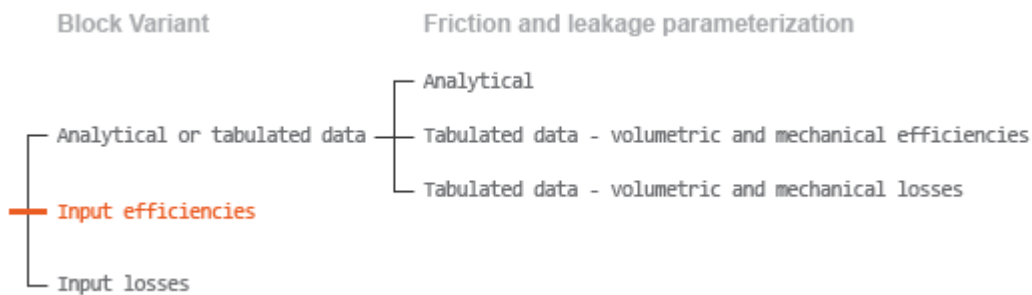
If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses, the leakage flow rate equation is

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega, D_{\text{Sat}}).$$

and the friction torque equation is

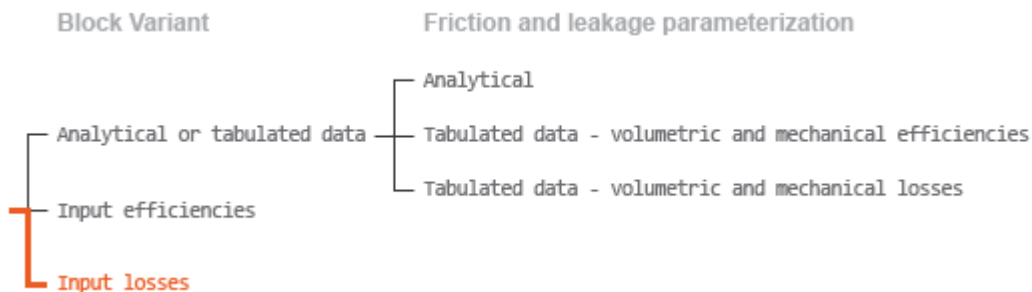
$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega, D_{\text{Sat}}),$$

where  $q_{\text{Leak}}(\Delta p, \omega, D_{\text{Sat}})$  and  $\tau_{\text{Friction}}(\Delta p, \omega, D_{\text{Sat}})$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the **Volumetric loss table,  $q_{\text{loss}}(\text{dp}, \text{w})$**  and **Mechanical loss table,  $\text{torque\_loss}(\text{dp}, \text{w})$**  parameter data.



#### Case 4: Efficiency Physical Signal Inputs

If the active block variant is Input efficiencies, the leakage flow rate and friction torque calculations are as described for efficiency tabulated data (case 2). The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports EV and EM.



#### Case 5: Loss Physical Signal Inputs

If the block variant is Input losses, the leakage flow rate and friction torque calculations are as described for loss tabulated data (case 3). The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports LV and LM.

#### Assumptions

- Fluid compressibility is negligible.
- Loading on the motor shaft due to inertia, friction, and spring forces is negligible.

## Ports

### Input

#### **C — Control member position, m**

physical signal

Physical signal input port for the control member position. The block maps the control member position to the corresponding displacement volume using the tabulated data specified in the block dialog box.

#### **Dependencies**

This port is exposed only when the block variant is set to `Analytical` or `tabulated data`.

#### **D — Displacement volume, cm<sup>3</sup>/rev**

physical signal

Physical signal input port for the volume of fluid displaced per unit rotation. A smoothing function eases the transition between positive and negative input values.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input efficiencies` or `Input losses`.

#### **EV — Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input efficiencies`.

#### **EM — Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input efficiencies`.

#### **LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the motor inlets.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input losses`.



**LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating motor shaft.

**Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

**Conserving****A — Motor inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the motor inlet.

**B — Motor outlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the motor outlet.

**S — Motor shaft**

mechanical rotational

Mechanical rotational conserving port representing the motor shaft.

**Parameters**

The exposed block parameters depend on the active block variant. See “Block Variants and Loss Parameterizations” on page 1-1956.

**Modeling option — Loss parameterizations**`Analytical or tabulated data | Input efficiencies | Input losses`

Set the variant for mechanical and volumetric efficiencies or losses for the block.

**Variant 1: Analytical or tabulated data****Displacement parameterization — Parameterization used to map control positions to displacements**`Maximum displacement and control member stroke (default)`

Parameterization used to convert the physical signal at input port C to an instantaneous displacement:

- `Maximum displacement and control member stroke` — Compute the displacement as a linear function of the control position specified at port C.
- `Displacement vs. control member position table` — Obtain the displacement through interpolation or extrapolation of tabulated data specified over a range of control positions.

**Restricted Parameter**

This parameter is locked for editing when using the Simscape Restricted mode.

**Maximum stroke — Control position corresponding to maximum displacement**

0.005 m (default) | scalar with units of length

Control position corresponding to a maximum displacement. The physical signal input at port C saturates at this value. If the input rises higher, the block sets the control position to the maximum stroke.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Maximum displacement and control member stroke.

**Maximum displacement — Maximum fluid volume swept per unit shaft rotation**

30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Maximum fluid volume swept per unit shaft rotation. The displacement reaches this value when the control position hits the maximum stroke.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Maximum displacement and control member stroke.

**Control member position vector — Control positions at which to specify displacement tabular data**

[-0.0075, -0.0025, 0.0, 0.0025, 0.0075] m (default) | *M*-element vector with units of length

*M*-element vector of control positions at which to specify the instantaneous displacement. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Displacement vector — Displacement tabular data for the specified control positions**

[-30.0, -19.0, 0.0, 19.0, 30.0] cm<sup>3</sup>/rev (default) | *M*-element vector with units of volume/angle

*M*-element vector with the displacement tabular data for the specified control positions. The vector size, *M*, must match that of the **Control member position vector** parameter.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Interpolation method — Numerical technique used to determine displacements within the tabular data range**

Linear (default) | Smooth

Numerical technique used to map control position signals to displacements within the tabular data range. The interpolation method joins tabular data points using straight or curved line segments. Displacements within the range of the tabular data are assumed to lie on these segments.

- **Linear** — Join neighboring data points using straight line segments. Line slopes are generally discontinuous at the line segment end points.
- **Smooth** — Join neighboring data points using curved line segments generated with a modified Akima algorithm. Line slopes are continuous at the line segment end points.

#### Dependencies

This parameter is enabled when the **Displacement parameterization** parameter is set to **Displacement vs. control member position table**.

#### Restricted Parameter

This parameter is locked for editing when using the Simscape Restricted mode.

#### Extrapolation method — Numerical technique used to determine displacements outside the tabular data range

Linear (default) | Nearest

Numerical technique used to map control position signals to displacements outside the tabular data range. The extrapolation method extends the first and last tabular data points outward using horizontal or sloped straight line segments. Displacements outside the range of the tabular data are assumed to lie on these segments.

- **Linear** — Extend the tabular data using sloped straight line segments. The line slopes are computed from the first and last two tabular data points.
- **Nearest** — Extend the tabular data using horizontal straight line segments. The lines correspond to the displacements specified in the first and last tabular data points.

#### Dependencies

This parameter is enabled when the **Displacement parameterization** parameter is set to **Displacement vs. control member position table**.

#### Restricted Parameter

This parameter is locked for editing when using the Simscape Restricted mode.

#### Leakage and friction parameterization — Parameterization used to compute leakage flow rate and friction torque

Analytical (default) | Tabulated data – volumetric and mechanical efficiencies |  
Tabulated data – volumetric and mechanical losses

Parameterization used to compute flow-rate and torque losses due to internal leaks and friction. The **Analytical** parameterization relies on nominal parameters generally available from component data sheets. The remaining, **tabular**, options rely on lookup tables to map pressure drop, angular velocity, and displacement to component efficiencies or losses. The tabular options include:

- **Tabulated data – volumetric and mechanical efficiencies**
- **Tabulated data – volumetric and mechanical losses**

#### Nominal shaft angular velocity — Shaft angular velocity at which to specify the volumetric efficiency

188 rad/s (default) | scalar with units of angle/time

Angular velocity of the rotating shaft at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in

manufacturer's data sheets. The block uses this parameter to calculate, using simple linear functions, the leakage flow rate and friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal pressure drop — Pressure drop at which to specify the volumetric efficiency**

100e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal kinematic viscosity — Kinematic viscosity at which to specify the volumetric efficiency**

18 cSt (default) | scalar with units of area/time

Kinematic viscosity of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal fluid density — Fluid density at which to specify the volumetric efficiency**

900 kg/m<sup>3</sup> (default) | scalar with units of mass/volume

Mass density of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Volumetric efficiency at nominal conditions — Volumetric efficiency at the specified nominal conditions**

0.92 (default) | unitless scalar between 0 and 1

Volumetric efficiency, defined as the ratio of actual to ideal volumetric flow rates, at the specified nominal conditions. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**No-load torque – Minimum torque required to induce shaft rotation**

0.05 N\*m (default) | scalar with units of torque

Torque required to overcome seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Friction torque vs. pressure drop coefficient at maximum displacement – Proportionality constant at maximum displacement between friction torque and pressure drop**

0.6e-6 N\*m/Pa (default) | scalar with units of torque/pressure

Proportionality constant at maximum displacement between the friction torque on the mechanical shaft and the pressure drop from inlet to outlet.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Displacement threshold for motor-pump transition – Displacement below which the transition between motoring and pumping modes begins**

0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Pressure drop vector for efficiencies,  $dp$  – Pressure drops at which to specify the volumetric and mechanical efficiencies**

*M*-element vector with units of pressure (default)

*M*-element vector of pressure drops at which to specify the efficiency tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Shaft angular velocity vector for efficiencies,  $w$  – Angular velocities at which to specify the volumetric and mechanical efficiencies**

*N*-element vector with units of angular velocity (default)

*N*-element vector of shaft angular velocities at which to specify the efficiency tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Displacement vector for efficiencies,  $D$  – Displacements at which to specify the volumetric and mechanical efficiencies**

*L*-element vector with units of volume/angle (default)

*L*-element vector of displacements at which to specify the efficiency tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

**Volumetric efficiency table,  $e_v(dp,w,D)$  – Volumetric efficiencies at the specified pressure drops, angular velocities, and displacements**

unitless *M*-by-*N*-by-*L* matrix

*M*-by-*N*-by-*L* matrix with the volumetric efficiencies at the specified fluid pressure drops, shaft angular velocities, and displacements. The efficiencies must fall in the range of 0–1. *M*, *N*, and *L* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure drop vector for efficiencies,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.
- *L* is the number of vector elements in the **Displacement vector for efficiencies,  $D$**  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w,D)$  – Mechanical efficiencies at the specified pressure drops, angular velocities, and displacements**

unitless *M*-by-*N* matrix

$M$ -by- $N$ -by- $L$  matrix with the mechanical efficiencies corresponding to the specified fluid pressure drops, shaft angular velocities, and displacements. The efficiencies must fall in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector for efficiencies,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector for efficiencies,  $D$**  parameter.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motor and pump modes

1e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### Angular velocity threshold for motor-pump transition – Shaft angular velocity at which to initiate a smooth transition between pump and motor modes

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### Check if operating beyond the octants of supplied tabulated data – Simulation warning mode for operating conditions outside the range of tabulated data

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select Warning to be notified when the fluid pressure drop, shaft angular velocity, or instantaneous displacement cross outside the specified tabular data. The warning does not cause simulation to stop.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies or Tabulated data – volumetric and mechanical losses.

**Pressure drop vector for losses,  $dp$  — Pressure drops at which to specify the volumetric and mechanical losses**

*M*-element vector with units of pressure (default)

*M*-element vector of pressure drops at which to specify the loss tabular data. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

**Shaft angular velocity vector for losses,  $w$  — Angular velocities at which to specify the volumetric and mechanical losses**

*N*-element vector with units of angle/time (default)

*N*-element vector of shaft angular velocities at which to specify the loss tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

**Displacement vector for losses,  $D$  — Displacements at which to specify the volumetric and mechanical losses**

*L*-element vector with units of volume/angle (default)

*L*-element vector of displacements at which to specify the loss tabular data. The vector size, *N*, must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

**Volumetric loss table,  $q\_loss(dp,w,D)$  — Internal leakage flow rates at the specified pressure drops, angular velocities, and displacements**

*M*-by-*N*-by-*L* matrix with units of volume/time

*M*-by-*N*-by-*L* matrix with the volumetric losses at the specified fluid pressure drops, shaft angular velocities, and displacements. Volumetric loss is defined here as the internal leakage volumetric flow rate between port A and port B. *M*, *N*, and *L* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure drop vector for losses,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.
- *L* is the number of vector elements in the **Displacement vector for losses,  $D$**  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

**Mechanical loss table,  $torque\_loss(dp,w,D)$  — Friction torques at the specified pressure drops, angular velocities, and displacements**

*M*-by-*N*-by-*L* matrix with units of torque



$M$ -by- $N$ -by- $L$  matrix with the mechanical losses at the specified fluid pressure drops, shaft angular velocities, and displacements. Mechanical loss is defined here as the friction torque due to seals and internal components.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector for losses,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector for losses,  $D$**  parameter.

### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

### Variant 2: Input efficiencies

#### Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal falls below the minimum volumetric efficiency, the volumetric efficiency is set to the minimum volumetric efficiency.

#### Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal rises above the maximum volumetric efficiency, the volumetric efficiency is set to the maximum volumetric efficiency.

#### Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal falls below the minimum mechanical efficiency, the mechanical efficiency is set to the minimum mechanical efficiency.

#### Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at this value. If the input signal rises above the maximum mechanical efficiency, the mechanical efficiency is set to the maximum mechanical efficiency.

#### Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motor and pump modes

1e5 Pa (default) | scalar with units of pressure

Pressure drop from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Displacement threshold for motor-pump transition — Displacement at which to initiate a smooth transition between pump and motor modes**0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition — Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure — Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Variant 3: Input losses****Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Displacement threshold for motor-pump transition — Displacement at which to initiate a smooth transition between pump and motor modes**0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Displacement threshold for motor-pump transition — Displacement below which the transition between motoring and pumping modes begins**0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if operating beyond the motor mode — Simulation warning mode for operating conditions outside motoring mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the motoring mode. A warning is issued if the motor transitions to pumping mode. Select Warning to be notified when this transition occurs. The warning does not cause simulation to stop.

**Check if lower side pressure violating minimum valid condition — Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure — Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Fixed-Displacement Motor | Fixed-Displacement Motor (TL) | Fixed-Displacement Pump | Fixed-Displacement Pump (TL) | Variable-Displacement Pump

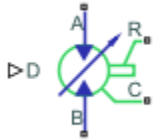
**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

## Variable-Displacement Motor (IL)

Variable-displacement motor in an isothermal liquid system

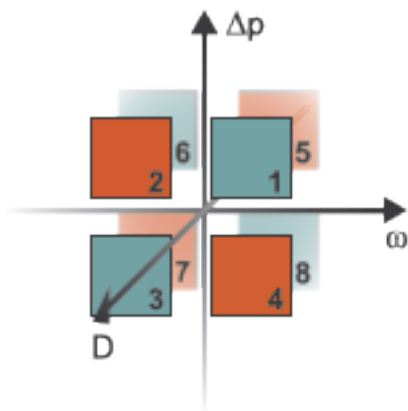
**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors



### Description

The Variable-Displacement Motor (IL) block models a motor with variable-volume displacement. The fluid may move from port **A** to port **B**, called *forward mode*, or from port **B** to port **A**, called *reverse mode*. Motor mode operation occurs when there is a pressure drop in the direction of the flow. Pump mode operation occurs when there is a pressure gain in the direction of the flow.

The shaft rotation corresponds to the sign of the fluid volume moving through the motor, which is received as a physical signal at port **D**. Positive fluid displacement at **D** corresponds to positive shaft rotation in forward mode. Negative fluid displacement at **D** corresponds to negative shaft angular velocity in forward mode.



### Operation Modes

The block has eight modes of operation. The working mode depends on the pressure drop from port **A** to port **B**,  $\Delta p = p_A - p_B$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement at port **D**. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- Mode 1, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 2, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to port **A**.

- Mode 3, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and a negative shaft angular velocity.
- Mode 4, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.
- Mode 5, *Reverse Pump*: Positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.
- Mode 6, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 7, *Forward Pump*: Negative shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.
- Mode 8, *Reverse Motor*: Flow from **B** to **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.

The motor block has analytical, lookup table, and physical signal parameterizations. When using tabulated data or an input signal for parameterization, you can choose to characterize the motor operation based on efficiency or losses.

The threshold parameters **Pressure drop threshold for motor-pump transition**, **Angular velocity threshold for motor-pump transition**, and **Displacement threshold for motor-pump transition** identify regions where numerically smoothed flow transition between the motor operational modes can occur. For the pressure and angular velocity thresholds, choose a transition region that provides some margin for the transition term, but which is small enough relative to the typical motor pressure drop and angular velocity so that it will not impact calculation results. For the displacement threshold, choose a threshold value that is smaller than the typical displacement volume during normal operation.

### Analytical Leakage and Friction Parameterization

If you set **Leakage and friction parameterization** to `Analytical`, the block calculates internal leakage and shaft friction from constant nominal values of shaft velocity, pressure drop, volumetric displacement, and torque. The leakage flow rate, which is correlated with the pressure differential over the motor, is calculated as:

$$\dot{m}_{leak} = K\rho_{avg}\Delta p,$$

where:

- $\Delta p$  is  $p_A - p_B$ .
- $\rho_{avg}$  is the average fluid density.
- $K$  is the Hagen-Poiseuille coefficient for analytical loss,

$$K = \frac{D_{nom}\omega_{nom}\left(\frac{1}{\eta_{v,nom}} - 1\right)}{\Delta p_{nom}},$$

where:

- $D_{nom}$  is the **Nominal displacement**.
- $\omega_{nom}$  is the **Nominal shaft angular velocity**.
- $\eta_{nom}$  is the **Volumetric efficiency at nominal conditions**.

- $\Delta p_{nom}$  is the **Nominal pressure drop**.

The torque, which is related to the motor pressure differential, is calculated as:

$$\tau_{fr} = \left( \tau_0 + k \left| \Delta p \frac{D}{D_{nom}} \right| \right) \tanh \left( \frac{4\omega}{5 \times 10^{-5} \omega_{nom}} \right),$$

where:

- $\tau_0$  is the **No-load torque**.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = (1 - \eta_{m,nom}) D_{nom} \Delta p_{nom}.$$

- $\Delta p$  is the pressure drop between ports **A** and **B**.
- $\omega$  is the relative shaft angular velocity, or  $\omega_R - \omega_C$ .

### Tabulated Data Parameterizations

When using tabulated data for motor efficiencies or losses, you can provide data for one or more of the motor operational modes. The signs of the tabulated data determine the operational regime of the block. When data is provided for less than eight operational modes, the block calculates the complementing data for the other mode(s) by extending the given data into the remaining octants.

#### The Tabulated data - volumetric and mechanical efficiencies parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \dot{m}_{leak,motor} \left( \frac{1 + \alpha}{2} \right) + \dot{m}_{leak,pump} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\dot{m}_{leak,pump} = (\eta_v - 1) \dot{m}_{ideal}$
- $\dot{m}_{leak,motor} = (1 - \eta_v) \dot{m}$

and  $\eta_v$  is the volumetric efficiency, which is interpolated from the user-provided tabulated data. The transition term,  $\alpha$ , is

$$\alpha = \tanh \left( \frac{4\Delta p}{\Delta p_{threshold}} \right) \tanh \left( \frac{4\omega}{\omega_{threshold}} \right) \tanh \left( \frac{4D}{D_{threshold}} \right),$$

where:

- $\Delta p$  is  $p_A - p_B$ .
- $\Delta p_{threshold}$  is the **Pressure drop threshold for motor-pump transition**.
- $\omega$  is  $\omega_R - \omega_C$ .

- $\omega_{\text{threshold}}$  is the **Angular velocity threshold for motor-pump transition**.

The torque is calculated as:

$$\tau_{fr} = \tau_{fr, pump} \left( \frac{1 + \alpha}{2} \right) + \tau_{fr, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\tau_{fr, pump} = (\eta_m - 1)\tau$
- $\tau_{fr, motor} = (1 - \eta_m)\tau_{ideal}$

and  $\eta_m$  is the mechanical efficiency, which is interpolated from the user-provided tabulated data.

### The Tabulated data - volumetric and mechanical losses parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{loss}(\Delta p, \omega, D),$$

where  $q_{loss}$  is interpolated from the **Volumetric loss table,  $q_{loss}(dp, w, D)$**  parameter, which is based on user-supplied data for pressure drop, shaft angular velocity, and fluid volumetric displacement.

The shaft friction torque is calculated as:

$$\tau_{fr} = \tau_{loss}(\Delta p, \omega, D),$$

where  $\tau_{loss}$  is interpolated from the **Mechanical loss table, torque\_loss(dp, w, D)** parameter, which is based on user-supplied data for pressure drop, shaft angular velocity, and fluid volumetric displacement.

### Input Signal Parameterization

When **Leakage and friction parameterization** is set to **Input signal - volumetric and mechanical efficiencies**, ports **EV** and **EM** are enabled. The internal leakage and shaft friction are calculated in the same way as the **Tabulated data - volumetric and mechanical efficiencies** parameterization, except that  $\eta_v$  and  $\eta_m$  are received directly at ports **EV** and **EM**, respectively.

When **Leakage and friction parameterization** is set to **Input signal - volumetric and mechanical losses**, ports **LV** and **LM** are enabled. These ports receive leakage flow and friction torque as positive physical signals. The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{LV} \tanh\left(\frac{4\Delta p}{p_{thresh}}\right),$$

where:

- $q_{LV}$  is the leakage flow received at port **LV**.
- $p_{thresh}$  is the **Pressure drop threshold for motor-pump transition** parameter.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{LM} \tanh\left(\frac{4\omega}{\omega_{thresh}}\right),$$

where

- $\tau_{LM}$  is the friction torque received at port **LM**.
- $\omega_{thresh}$  is the **Angular velocity threshold for motor-pump transition** parameter.

The volumetric and mechanical efficiencies range between the user-defined specified minimum and maximum values. Any values lower or higher than this range will take on the minimum and maximum specified values, respectively.

### Motor Operation

The motor flow rate is:

$$\dot{m} = \dot{m}_{ideal} + \dot{m}_{leak},$$

where  $\dot{m}_{ideal} = \rho_{avg} D \cdot \omega$ .

The motor torque is:

$$\tau = \tau_{ideal} - \tau_{fr},$$

where  $\tau_{ideal} = D \cdot \Delta p$ .

The mechanical power extracted by the motor shaft is:

$$\varphi_{mech} = \tau \omega,$$

and the motor hydraulic power is:

$$\varphi_{hyd} = \frac{\Delta p \dot{m}}{\rho_{avg}}.$$

To be notified if the block is operating beyond the supplied tabulated data, you can set **Check if operating beyond the octants of supplied tabulated data** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs. When using input signal for volumetric or mechanical losses, you can be notified if the simulation surpasses operating modes with the **Check if operating beyond motor mode** parameter.

You can also monitor motor functionality. Set **Check if pressures are less than motor minimum pressure** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port to the motor.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port to the motor.



**R – Mechanical port**

mechanical rotational

Rotating shaft angular velocity and torque.

**C – Mechanical port**

mechanical rotational

Motor casing reference angular velocity and torque.

**Input****D – Volumetric displacement,  $m^3/rad$** 

physical signal

Volumetric displacement of the motor, in  $m^3/rad$ , specified as a physical signal.**EV – Volumetric efficiency**

physical signal

Motor efficiency for fluid displacement, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.**EM – Mechanical efficiency**

physical signal

Motor efficiency for the mechanical extraction of energy, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.**LV – Leakage flow rate,  $m^3/s$** 

physical signal

Motor volumetric losses, in  $m^3/s$ , specified as a physical signal.**Dependencies**To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.**LM – Friction torque,  $N*m$** 

physical signal

Motor mechanical losses in  $N*m$ , specified as a physical signal.**Dependencies**To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Parameters

### Leakage and friction parameterization — Method of calculating leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Parameterization of the leakage and friction characteristics of the motor.

- In the **Analytical** parameterization, the leakage flow rate and the friction torque are calculated by analytical equations.
- In the **Tabulated data - volumetric and mechanical efficiencies** parameterization, the leakage flow rate and torque friction are calculated from the user-supplied **Pressure drop vector,  $dp$** , **Shaft angular velocity vector,  $w$** , and **Displacement vector,  $D$**  parameters and interpolated from the 3-D dependent **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  tables.
- In the **Tabulated data - volumetric and mechanical loss** parameterization, the leakage flow rate and torque friction are calculated from the user-supplied **Pressure drop vector,  $dp$** ; **Shaft angular velocity vector,  $w$** ; and **Displacement vector,  $D$**  parameters and interpolated from the 3-D dependent **Volumetric loss table,  $q_{loss}(dp,w,D)$**  and **Mechanical loss table,  $torque_{loss}(dp,w,D)$**  tables.
- In the **Input signal - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are received as physical signals at ports **EV** and **EM**, respectively.
- In the **Input signal - volumetric and mechanical loss** parameterization, the leakage flow rate and friction torque are received as physical signals at ports **LV** and **LM**, respectively.

### Nominal displacement — Fixed-volume fluid displacement

30 cm<sup>3</sup>/rev (default) | scalar

Amount of fluid displaced by shaft rotating under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Nominal shaft angular velocity — Shaft angular velocity

188 rad/s (default) | scalar

Angular velocity of the shaft under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

### Nominal pressure drop — Pressure drop between fluid entry and exit

10 MPa (default) | scalar

Motor pressure drop between the fluid entry and exit under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

**Volumetric efficiency at nominal conditions – Ratio of actual flow rate to ideal flow rate at nominal conditions**

0.92 (default) | positive scalar in the range of (0,1]

Ratio of actual flow rate to ideal flow rate at nominal conditions.

**Dependencies**To enable this parameter, set **Leakage and friction parameterization** to Analytical.**No-load torque – Baseline torque**

0 N\*m (default) | scalar

Minimum value of torque to overcome seal friction and induce shaft motion.

**Dependencies**To enable this parameter, set **Leakage and friction parameterization** to Analytical.**Mechanical efficiency at nominal conditions – Ratio of actual to ideal mechanical power**

0.88 (default) | positive scalar

Ratio of actual mechanical power to ideal mechanical power at nominal conditions.

**Dependencies**To enable this parameter, set **Leakage and friction parameterization** to Analytical.**Pressure drop vector,  $dp$  – Vector of pressure data for tabulated data parameterization**[.1, 1, 2] MPa (default) | 1-by- $n$  vector

Vector of pressure differential values for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector,  $w$**  and the **Displacement vector,  $D$**  parameters for the 3-D dependent **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  parameters. The vector elements must be listed in ascending order.

**Dependencies**To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Shaft angular velocity vector,  $w$  – Vector of angular velocity data for tabulated data parameterization**[25, 50, 100, 200, 300, 400] rad/s (default) | 1-by- $n$  vector

Vector of angular velocity data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector,  $w$**  and the **Displacement vector,  $D$**  parameters for the 3-D dependent **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Displacement vector, D – Vector of displacement volumes for tabulated data parameterization**

`[-30, -19, 19, 30]` cm<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of volumetric displacement data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** and the **Pressure drop vector, dp** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Volumetric efficiency table, e\_v(dp,w,D) – Volumetric efficiency for tabulated data parameterization**

`repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4)` (default) | *M*-by-*N*-by-*P* matrix

*M*-by-*N*-by-*P* matrix of volumetric efficiencies at the specified fluid pressure drop, shaft angular velocity, and volumetric displacement. Linear interpolation is employed between table elements. *M*, *N*, and *P* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Pressure drop vector, dp** parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector, w** parameter.
- *P* is the number of vector elements in the **Displacement vector, D** parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table, e\_m(dp,w,D) – Mechanical efficiency for tabulated data parameterization**

`repmat([.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984], 1, 1, 4)` (default) | *M*-by-*N*-by-*P* matrix

*M*-by-*N*-by-*P* matrix of mechanical efficiencies at the specified fluid pressure drop, shaft angular velocity, and displacement. Linear interpolation is employed between table elements. *M*, *N*, and *P* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Pressure drop vector, dp** parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector, w** parameter.

- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Volumetric loss table, $q\_loss(dp,w,D)$ — Volumetric losses for tabulated data parameterization

```
repmat([.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125, .108; .1079, .108, .11, .108, .1605, .18] * 1e-3, 1, 1, 4) (default) | M-by-N-by-P matrix
```

$M$ -by- $N$ -by- $P$  matrix of volumetric leakage at the specified fluid pressure drop, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

#### Mechanical loss table, $torque\_loss(dp,w,D)$ — Mechanical losses for tabulated data parameterization

```
repmat([.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556, .0505; .1937, .1937, .1833, .1833, .1729, .1626], 1, 1, 4) N*m (default) | M-by-N-by-P matrix
```

$M$ -by- $N$ -by- $P$  matrix of mechanical losses at the specified fluid pressure drop and shaft angular velocity. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the correlated vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

#### Minimum volumetric efficiency — Minimum value of volumetric efficiency

$1e-3$  (default) | positive scalar in the range of (0,1]

Minimum value of volumetric efficiency. If the input signal is below this value, the volumetric efficiency is set to the minimum volumetric efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum volumetric efficiency – Maximum value of volumetric efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of volumetric efficiency. If the input signal is above this value, the volumetric efficiency is set to the maximum volumetric efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Minimum mechanical efficiency – Minimum value of mechanical efficiency**

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of mechanical efficiency. If the input signal is below this value, the mechanical efficiency is set to the minimum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency – Maximum value of mechanical efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of mechanical efficiency. If the input signal is above this value, the mechanical efficiency is set to the maximum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure drop threshold for motor-pump transition – Pressure threshold for mode transition**

1e-3 MPa (default) | positive scalar

Motor pressure drop that indicates the transition threshold between motor and pump functionality. A transition region is defined around 0 MPa between the positive and negative values of the pressure drop threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Angular velocity threshold for motor-pump transition – Angular velocity threshold for mode transition**

10 rad/s (default) | positive scalar

Shaft angular velocity that indicates the transition threshold between motor and pump functionality. A transition region is defined around 0 rad/s between the positive and negative values of the angular

velocity threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

#### Displacement threshold for motor-pump transition — Displacement threshold for mode transition

0.1 cm<sup>3</sup>/s (default) | positive scalar

Volumetric displacement that indicates the transition threshold between motor and pump functionality. A transition region is defined around 0 cm<sup>3</sup>/s between the positive and negative values of the displacement threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other. It is also used to transition the ideal mass flow rate when the sign of **D** changes.

#### Check if operating beyond the octants of supplied tabulated data — Whether to notify if extents of supplied data are surpassed

None (default) | Warning | Error

Whether to notify if the extents of the supplied data are surpassed. Select Warning to be notified when the block uses values beyond the supplied data range. Select Error to stop the simulation when the block uses values beyond the supplied data range.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

#### Check if operating beyond motor mode — Whether to notify if block operates outside of the motor mode functionality

None (default) | Warning | Error

Whether to notify if the block operates outside of the motor mode functionality. Select Warning to be notified when the block operates in the forward or reverse pump modes. Select Error to stop the simulation when the block operates in the forward or reverse pump modes.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

#### Check if pressures are less than motor minimum pressure — Whether to notify if fluid exit pressure is low

None (default) | Warning | Error

Whether to notify if the fluid at port **A** or **B** experiences low pressure. Select **Warning** to be notified when the pressure falls below a minimum specified value. Select **Error** to stop the simulation when the pressure falls below a minimum specified value.

The parameter helps identify potential conditions for cavitation, when the fluid pressure falls below the fluid vapor pressure.

**Motor minimum pressure — Lower threshold of acceptable pressure at the motor outlet**

0.101325 MPa (default) | positive scalar

Lower threshold of acceptable pressure at the motor inlet or outlet.

**Dependencies**

To enable this parameter, set **Check if pressures are less than motor minimum pressure** to either:

- Warning
- Error

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Variable-Displacement Motor (TL) | Variable-Displacement Pump (IL) | Fixed-Displacement Motor (IL)



## Variable-Displacement Motor (TL)

Variable-displacement bidirectional thermal liquid motor

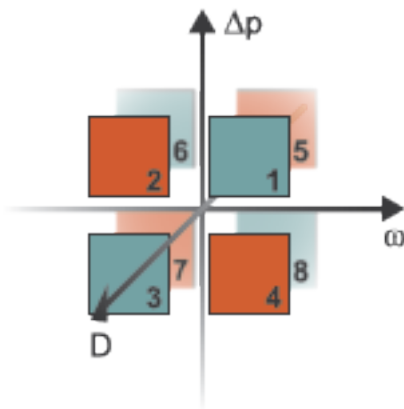
**Library:** Simscape / Fluids / Thermal Liquid / Pumps & Motors



### Description

The Variable-Displacement Motor block represents a device that extracts power from a thermal liquid network and delivers it to a mechanical rotational network. The motor displacement varies during simulation according to the physical signal input specified at port **D**.

Ports **A** and **B** represent the motor inlets. Ports **R** and **C** represent the motor drive shaft and case. During normal operation, a pressure drop from port **A** to port **B** causes a positive flow rate from port **A** to port **B** and a positive rotation of the motor shaft relative to the motor case. This operation mode is referred to here as *forward motor*.



### Operation Modes

The block has eight modes of operation. The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement at port **D**. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- Mode 1, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 2, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to port **A**.
- Mode 3, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and a negative shaft angular velocity.

- Mode 4, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.
- Mode 5, *Reverse Pump*: Positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.
- Mode 6, *Forward Motor*: Flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and a positive shaft angular velocity.
- Mode 7, *Forward Pump*: Negative shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from **A** to **B**.
- Mode 8, *Reverse Motor*: Flow from **B** to **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.

The response time of the motor is considered negligible in comparison with the system response time. The motor is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.

### **Flow Rate and Driving Torque**

The mass flow rate generated at the motor is

$$\dot{m} = \dot{m}_{\text{Ideal}} + \dot{m}_{\text{Leak}},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{\text{Ideal}}$  is the ideal mass flow rate.
- $\dot{m}_{\text{Leak}}$  is the internal leakage mass flow rate.

The torque generated at the motor is

$$\tau = \tau_{\text{Ideal}} - \tau_{\text{Friction}},$$

where:

- $\tau$  is the actual torque.
- $\tau_{\text{Ideal}}$  is the ideal torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### **Ideal Flow Rate and Ideal Torque**

The ideal mass flow rate is

$$\dot{m}_{\text{Ideal}} = \rho D \omega,$$

and the ideal generated torque is

$$\tau_{\text{Ideal}} = D \Delta p,$$

where:

- $\rho$  is the average of the fluid densities at thermal liquid ports **A** and **B**.
- $D$  is the displacement specified at physical signal port **D**.

- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure drop from inlet to outlet.

### Leakage and friction parameterization

You can parameterize leakage and friction analytically, using tabulated efficiencies or losses, or by input efficiencies or input losses.

#### Analytical

When you set **Leakage and friction parameterization** to Analytical leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}}\rho_{\text{Avg}}\Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}}|\Delta p|\frac{|D|}{D_{\text{Nom}}}\tanh\left(\frac{4\omega}{(5e-5)\omega_{\text{Nom}}}\right) \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the thermal liquid, taken here as the average of its values at the thermal liquid ports.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = (1 - \eta_{m,nom})D_{nom}\Delta p_{nom}.$$

- $D_{\text{Nom}}$  is the specified value of the **Nominal Displacement** block parameter.
- $\tau_0$  is the specified value of the **No-load torque** block parameter.
- $\omega_{\text{Nom}}$  is the specified value of the **Nominal shaft angular velocity** block parameter.
- $\Delta p_{\text{Nom}}$  is the specified value of the **Nominal pressure drop** block parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.

The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{\text{HP}} = \frac{D_{\text{Nom}}\omega_{\text{Nom}}\mu_{\text{Nom}}\left(\frac{1}{\eta_{v,\text{Nom}}} - 1\right)}{\Delta p_{\text{Nom}}},$$

where:

- $\omega_{\text{Nom}}$  is the specified value of the **Nominal shaft angular velocity** parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.

- $\mu_{\text{Nom}}$  is the specified value of the **Nominal Dynamic viscosity** block parameter. This is the dynamic viscosity at which the nominal volumetric efficiency is specified.
- $\eta_{\text{v,Nom}}$  is the specified value of the **Volumetric efficiency at nominal conditions** block parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.

### Tabulated Efficiencies

When you set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \dot{m}_{\text{Leak,Pump}} \frac{(1 + \alpha)}{2} + \dot{m}_{\text{Leak,Motor}} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{\text{Friction}} = \tau_{\text{Friction,Pump}} \frac{1 + \alpha}{2} + \tau_{\text{Friction,Motor}} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\dot{m}_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic tangent function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4D}{D_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure gain threshold for pump-motor transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for pump-motor transition** block parameter.
- $D_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.

The leakage flow rate is calculated from the volumetric efficiency, a quantity that is specified in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain via the **Volumetric efficiency table** block parameter. When operating in pump mode (octants **1** and **3** of the  $\Delta p$ - $\omega$ - $D$  chart shown in the "Operation Modes" on page 1-793 figure), the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = (1 - \eta_{\text{v}})\dot{m}_{\text{Ideal}},$$

where  $\eta_{\text{v}}$  is the volumetric efficiency, obtained either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode (octants **2** and **4** of the  $\Delta p$ - $\omega$ - $D$  chart), the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = -(1 - \eta_{\text{v}})\dot{m}.$$

The friction torque is similarly calculated from the mechanical efficiency, a quantity that is specified in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain via the **Mechanical efficiency table** block parameter. When operating in pump mode (octants **1** and **3** of the  $\Delta p$ - $\omega$ - $D$  chart):

$$\tau_{\text{Friction,Pump}} = (1 - \eta_m)\tau,$$

where  $\eta_m$  is the mechanical efficiency, obtained either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode (octants **2** and **4** of the  $\Delta p$ - $\omega$ - $D$  chart):

$$\tau_{\text{Friction,Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}}.$$

### Tabulated Losses

When you set **Leakage and friction parameterization** to **Tabulated data - volumetric and mechanical losses**, the leakage (volumetric) flow rate is specified directly in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega, D).$$

The mass flow rate due to leakage is calculated from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The friction torque is similarly specified in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega, D),$$

where  $q_{\text{Leak}}(\Delta p, \omega, D)$  and  $\tau_{\text{Friction}}(\Delta p, \omega, D)$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the tabulated data specified via the **Volumetric loss table** and **Mechanical loss table** block parameters.

### Input Efficiencies

When you set **Leakage and friction parameterization** to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports **EV** and **EM**.

The efficiencies are positive quantities with value between 0 and 1. Input values outside of these bounds are set equal to the nearest bound (0 for inputs smaller than 0, 1 for inputs greater than 1). The efficiency signals are saturated at the **Minimum volumetric efficiency** or **Minimum mechanical efficiency** and **Maximum volumetric efficiency** or **Maximum mechanical efficiency**.

### Input Losses

When you set **Leakage and friction parameterization** to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports **LV** and **LM**.

The block expects the inputs to be positive. It sets the signs automatically from the operating conditions established during simulation—more precisely, from the  $\Delta p$ - $\omega$  quadrant in which the component happens to be operating.

## Energy Balance

Mechanical work done by the motor is associated with an energy exchange. The governing energy balance equation is:

$$\phi_A + \phi_B - P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is a function of the pressure difference between motor ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$ .

The motor mechanical power is generated due to torque,  $\tau$ , and angular velocity,  $\omega$ :

$$P_{mech} = \tau\omega.$$

## Assumptions

- Fluid compressibility is negligible.
- Loading on the motor shaft due to inertia, friction, and spring forces is negligible.

## Ports

### Input

#### **D — Displacement volume, cm<sup>3</sup>/rev**

physical signal

Physical signal input port for the volume of fluid displaced per rotation. A smoothing function eases the transition between positive and negative input values.

#### **EV — Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

#### **Dependencies**

This port is exposed only when the block variant is set to Input efficiencies.

#### **EM — Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

#### **Dependencies**

This port is exposed only when the block variant is set to Input efficiencies.

#### **LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the motor inlets.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

#### **LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating motor shaft.

#### **Dependencies**

This port is exposed only when the block variant is set to `Input losses`.

#### **Conserving**

##### **A — Motor inlet**

thermal liquid

Thermal liquid conserving port representing the motor inlet.

##### **B — Motor outlet**

thermal liquid

Thermal liquid conserving port representing the motor outlet.

##### **C — Motor Case**

mechanical rotational

Mechanical rotational conserving port representing the motor case.

##### **R — Motor Shaft**

mechanical rotational

Mechanical rotational conserving port representing the rotational motor shaft.

## **Parameters**

### **Leakage and friction parameterization — Parameterization of leakage flow rate and friction torque**

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute flow-rate and torque losses due to internal leaks and friction. When you select `Analytical`, the block parameters are generally available from component data sheets. When you select `Tabulated data - volumetric and mechanical efficiencies` or `Tabulated data - volumetric and mechanical losses`, the block uses lookup tables to map pressure drop, angular velocity, and displacement to component efficiencies or losses.

When you select `Input signal - volumetric and mechanical efficiencies` or `Input signal - volumetric and mechanical losses`, the block performs the leakage flow rate and

friction torque calculations the same as the Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses settings, respectively. When you select Input signal - volumetric and mechanical efficiencies the block enables the physical signal ports, **EV** and **EM**. You use these ports to specify the volumetric and mechanical efficiency. When you select Input signal - volumetric and mechanical losses the block enables the physical signal ports, **LV** and **LM**. You use these ports to specify the volumetric and mechanical losses.

**Nominal displacement — Displacement at which to specify the volumetric efficiency**

30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid displacement for a given volumetric efficiency. These values are typically available at standard operating conditions in the manufacturer data sheet. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Nominal shaft angular velocity — Shaft angular velocity for given volumetric efficiency**

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. These values are typically available at standard operating conditions in the manufacturer data sheet. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal pressure drop — Pressure drop for corresponding volumetric efficiency**

10 MPa (default) | scalar

Pressure drop that corresponds to the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Nominal dynamic viscosity — Dynamic viscosity at which to specify the volumetric efficiency**

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Volumetric efficiency at nominal conditions — Volumetric efficiency at the specified nominal conditions**

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. These values are typically available at standard operating



conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Mechanical efficiency at nominal conditions – Ratio of actual to ideal mechanical power

0.88 (default) | positive scalar

Ratio of actual mechanical power to ideal mechanical power at nominal conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### No-load torque – Minimum torque required to induce shaft rotation

0 N\*m (default) | scalar

Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Pressure drop vector, dp – Pressure drops for given volumetric and mechanical efficiencies

[.1, 1, 2] MPa (default) | vector

Pressure drops for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant, ( $\omega$ ,  $\Delta p$ ,  $D$ ). Refer to the block description for the operation modes corresponding to the various octant.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Shaft angular velocity vector, w – Angular velocities at which to specify the volumetric and mechanical efficiencies

[25, 50, 100, 200, 300, 400] rad/s | vector

Shaft angular velocities for the corresponding tabular efficiency data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant, ( $\omega$ ,  $\Delta p$ ,  $D$ ). Refer to the block description for the operation modes corresponding to the various octants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Displacement vector,  $D$  — Displacements at which to specify the volumetric and mechanical efficiencies**

`[-30, -19, 19, 30] cm3/rev (default)`

Displacements at which to specify the efficiency tabular data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric efficiency table,  $e_v(dp,w,D)$  — Volumetric efficiencies for given pressure drops, angular velocities, and displacements**

```
repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4) | matrix
```

Volumetric efficiencies at the specified fluid pressure drops, shaft angular velocities, and displacements. The efficiencies must be in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w,D)$  — Mechanical efficiencies for given pressure drops, angular velocities, and displacements**

```
repmat([.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984], 1, 1, 4) | matrix
```

Mechanical efficiencies corresponding to the specified fluid pressure drops, shaft angular velocities, and displacements. The efficiencies must be in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Pressure drop vector,  $dp$  — Pressure drop for corresponding losses**

[.1, 1, 2] MPa (default)

Pressure drops for the corresponding tabular loss data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Shaft angular velocity vector,  $w$  — Shaft speed for corresponding losses**

[25, 50, 100, 200, 300, 400] rad/s (default)

Shaft angular velocity for the corresponding tabular loss data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Displacement vector,  $D$  — Displacements at which to specify the volumetric and mechanical losses**

[-30, -19, 19, 30] cm<sup>3</sup>/rev (default)

Displacements at which to specify the loss tabular data. The vector must be at least two elements in strictly increasing order.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Volumetric loss table,  $q_{\text{loss}}(dp, w, D)$  — Internal leakage flow rates for corresponding pressure drops, angular velocities, and displacements**

repmat([.0282, .0253, .0241, .0235, .0291, .0325; .2596, .1271, .1017, .0917, .1216, .1142; .7874, .1901, .141, .1211, .1797, .1978] \* 1e-3, 1, 1, 4) m<sup>3</sup>/s

Volumetric losses at the specified fluid pressure drops, shaft angular velocities, and displacements. The block defines volumetric loss the internal leakage volumetric flow rate between port **A** and port **B**.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

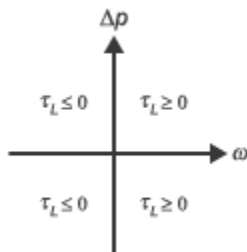
### Mechanical loss table, torque\_loss(dp,w,D) – Friction torques for the corresponding pressure drops, angular velocities, and displacements

```
repmat([.002, .002, .002, .002, .002, .002; .06, .055, .055, .055, .055, .05; .19, .19, .18, .18, .17, .16], 1, 1, 4) N*m
```

Mechanical losses for the given pressure drops, shaft angular velocities, and displacements. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure drop vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

You can specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to the block description for the operation modes corresponding to the various octants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

### Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | scalar in the range (0,1)

Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure drop threshold for motor-pump transition – Pressure drop at which to initiate a smooth transition between motor and pump modes**

1e-3 MPa (default) | scalar

Pressure drop from inlet to outlet below which the block begins to transition between motoring and pumping modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between motoring and pumping modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Cross-sectional area at ports A and B — Flow area at the component inlet and outlet**0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

**Check if operating beyond the octants of supplied tabulated data — Simulation warning mode for operating conditions outside the range of tabulated data**

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select Warning to be notified when the fluid pressure drop, shaft angular velocity, or instantaneous displacement cross outside the specified tabular data. The warning does not cause simulation to stop.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Check if operating outside of motor mode — Simulation warning mode for operating conditions outside motoring mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the motoring mode. The block generates a warning if the motor transitions to pumping mode. Select Warning to be notified when this transition occurs. The warning does not cause simulation to stop.

## Version History

**Introduced in R2017b**

## Extended Capabilities

**C/C++ Code Generation**

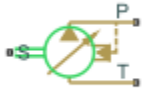
Generate C and C++ code using Simulink® Coder™.

**See Also**

Fixed-Displacement Pump (TL) | Fixed-Displacement Motor (TL)

# Variable-Displacement Pressure-Compensated Pump

Hydraulic pump maintaining preset pressure at outlet by regulating its flow delivery



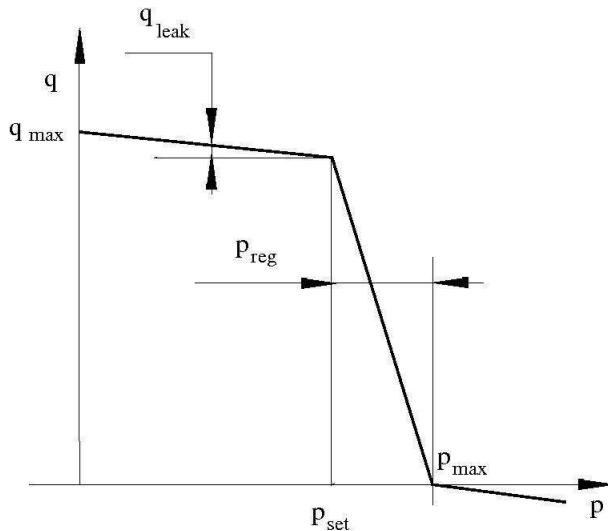
## Library

Pumps and Motors

## Description

The Variable-Displacement Pressure-Compensated Pump block represents a positive, variable-displacement, pressure-compensated pump of any type as a data-sheet-based model. The key parameters required to parameterize the block are the pump maximum displacement, regulation range, volumetric and total efficiencies, nominal pressure, and angular velocity. All these parameters are generally provided in the data sheets or catalogs.

The following figure shows the delivery-pressure characteristic of the pump.



The pump tries to maintain preset pressure at its outlet by adjusting its delivery flow in accordance with the system requirements. If pressure differential across the pump is less than the setting pressure, the pump outputs its maximum delivery corrected for internal leakage. After the pressure setting has been reached, the output flow is regulated to maintain preset pressure by changing the pump's displacement. The displacement can be changed from its maximum value down to zero, depending upon system flow requirements. The pressure range between the preset pressure and the



maximum pressure, at which the displacement is zero, is referred to as regulation range. The smaller the range, the higher the accuracy at which preset pressure is maintained. The range size also affects the pump stability, and decreasing the range generally causes stability to decrease.

The variable-displacement, pressure-compensated pump is represented with the following equations:

$$q = D \cdot \omega - k_{leak} \cdot p$$

$$T = D \cdot p / \eta_{mech}$$

$$D = \begin{cases} D_{max} & \text{for } p \leq p_{set} \\ D_{max} - K(p - p_{set}) & \text{for } p_{set} < p < p_{max} \\ 0 & \text{for } p \geq p_{max} \end{cases}$$

$$p_{max} = p_{set} + p_{reg}$$

$$K = D_{max} / (p_{max} - p_{set})$$

$$k_{leak} = \frac{k_{HP}}{\nu \cdot \rho}$$

$$k_{HP} = \frac{D_{max} \cdot \omega_{nom}(1 - \eta_V) \cdot \nu_{nom} \cdot \rho_{nom}}{p_{nom}}$$

$$p = p_P - p_T$$

where

$q$	Pump delivery
$p$	Pressure differential across the pump
$p_P, p_T$	Gauge pressures at the block terminals
$D$	Pump instantaneous displacement
$D_{max}$	Pump maximum displacement
$p_{set}$	Pump setting pressure
$p_{max}$	Maximum pressure, at which the pump displacement is zero
$T$	Torque at the pump driving shaft
$\omega$	Pump angular velocity
$k_{leak}$	Leakage coefficient
$k_{HP}$	Hagen-Poiseuille coefficient
$\eta_V$	Pump volumetric efficiency
$\eta_{mech}$	Pump mechanical efficiency
$\nu$	Fluid kinematic viscosity
$\rho$	Fluid density
$\rho_{nom}$	Nominal fluid density
$p_{nom}$	Pump nominal pressure

$\omega_{nom}$	Pump nominal angular velocity
$\nu_{nom}$	Nominal fluid kinematic viscosity

The leakage flow is determined based on the assumption that it is linearly proportional to the pressure differential across the pump and can be computed by using the Hagen-Poiseuille formula

$$p = \frac{128\mu l}{\pi d^4} q_{leak} = \frac{\mu}{k_{HP}} q_{leak}$$

where

$q_{leak}$	Leakage flow
$d, l$	Geometric parameters of the leakage path
$\mu$	Fluid dynamic viscosity, $\mu = \nu\rho$

The leakage flow at  $p = p_{nom}$  and  $\nu = \nu_{nom}$  can be determined from the catalog data

$$q_{leak} = D_{max} \cdot \omega_{nom}(1 - \eta_V)$$

which provides the formula to determine the Hagen-Poiseuille coefficient

$$k_{HP} = \frac{D_{max} \cdot \omega_{nom}(1 - \eta_V) \cdot \nu_{nom} \cdot \rho_{nom}}{p_{nom}}$$

The pump mechanical efficiency is not usually available in data sheets, therefore it is determined from the total and volumetric efficiencies by assuming that the hydraulic efficiency is negligibly small

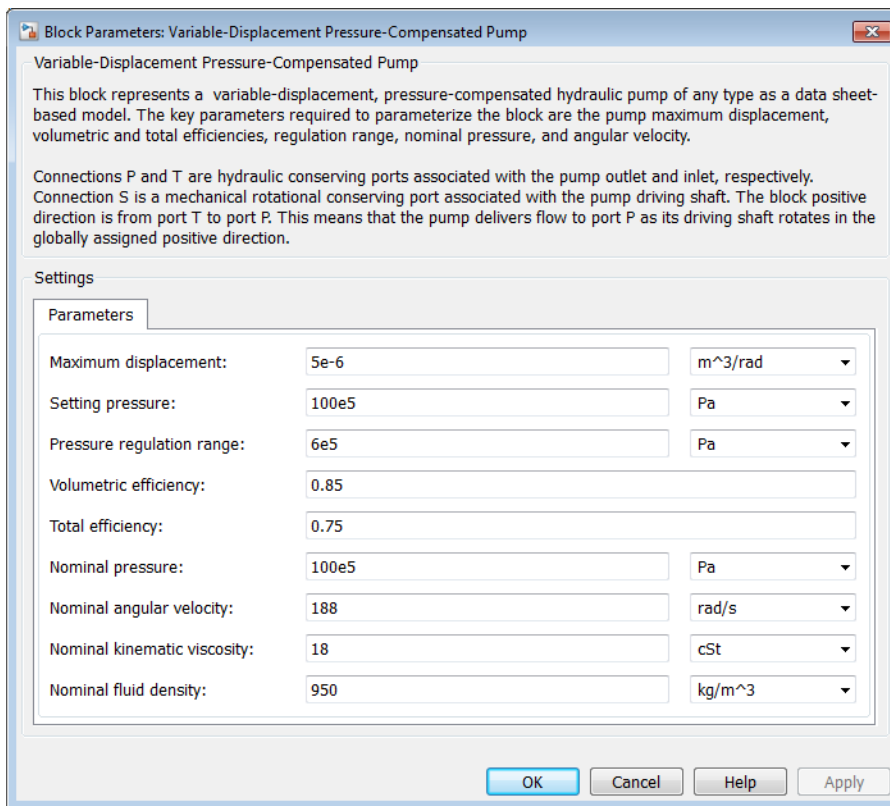
$$\eta_{mech} = \eta_{total} / \eta_V$$

The block positive direction is from port T to port P. This means that the pump transfers fluid from T to P provided that the shaft S rotates in the positive direction. The pressure differential across the pump is determined as  $p = p_P - p_T$ .

## Basic Assumptions and Limitations

- Fluid compressibility is neglected.
- No loading on the pump shaft, such as inertia, friction, spring, and so on, is considered.
- Leakage inside the pump is assumed to be linearly proportional to its pressure differential.

## Dialog Box and Parameters



### Maximum displacement

Pump displacement. The default value is  $5e-6 \text{ m}^3/\text{rad}$ .

### Setting pressure

Pump pressure setting. The default value is  $1e7 \text{ Pa}$ .

### Pressure regulation range

Pressure range required to change the pump displacement from its maximum to zero. The default value is  $6e5 \text{ Pa}$ .

### Volumetric efficiency

Pump volumetric efficiency specified at nominal pressure, angular velocity, and fluid viscosity. The default value is  $0.85$ .

### Total efficiency

Pump total efficiency, which is determined as a ratio between the hydraulic power at the pump outlet and mechanical power at the driving shaft at nominal pressure, angular velocity, and fluid viscosity. The default value is  $0.75$ .

### Nominal pressure

Pressure differential across the pump, at which both the volumetric and total efficiencies are specified. The default value is  $1e7 \text{ Pa}$ .

### Nominal angular velocity

Angular velocity of the driving shaft, at which both the volumetric and total efficiencies are specified. The default value is  $188 \text{ rad/s}$ .

**Nominal kinematic viscosity**

Working fluid kinematic viscosity, at which both the volumetric and total efficiencies are specified. The default value is 18 cSt.

**Nominal fluid density**

Working fluid density, at which both the volumetric and total efficiencies are specified. The default value is 900 kg/m<sup>3</sup>.

**Global Parameters**

Parameter determined by the type of working fluid:

- **Fluid kinematic viscosity**

Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

**Ports**

The block has the following ports:

T

Hydraulic conserving port associated with the pump suction, or inlet.

P

Hydraulic conserving port associated with the pump outlet.

S

Mechanical rotational conserving port associated with the pump driving shaft.

**Examples**

The “Closed-Loop Actuator with Variable-Displacement Pressure-Compensated Pump” example illustrates the use of the Variable-Displacement Pressure-Compensated Pump block in hydraulic systems.

**Version History**

Introduced in R2006a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Centrifugal Pump | Fixed-Displacement Pump | Variable-Displacement Pump

**Topics**

“Upgrading Simscape Fluids Models Containing Hydraulics (Isothermal) Blocks”

# Variable-Displacement Pump

Variable-displacement bidirectional hydraulic pump

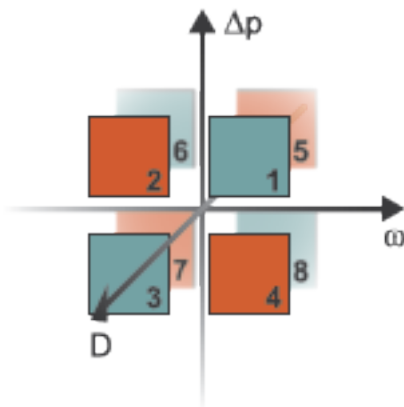
**Library:** Simscape / Fluids / Hydraulics (Isothermal) / Pumps and Motors



## Description

The Variable-Displacement Pump block represents a device that extracts power from a mechanical rotational network and delivers it to a hydraulic (isothermal liquid) network. The pump displacement varies in proportion to the physical signal specified at port C or D. The exact port used depends on the block variant selected. See “Ports” on page 1-2014.

Ports **T** and **P** represent the pump inlets. Port **S** represents the pump drive shaft. During normal operation, the pressure gain from port **T** to port **P** is positive if the angular velocity at port **S** is positive also. This operation mode is referred to here as *forward pump*.



## Operation Modes

A total of four operation modes are possible. The working mode depends on the pressure gain from port **T** to port **P** ( $\Delta p$ ), the angular velocity at port **S** ( $\omega$ ), and on the instantaneous displacement of the component ( $D$ ). The “Operation Modes” on page 1-2007 figure maps the modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart. The modes are labeled 1-4:

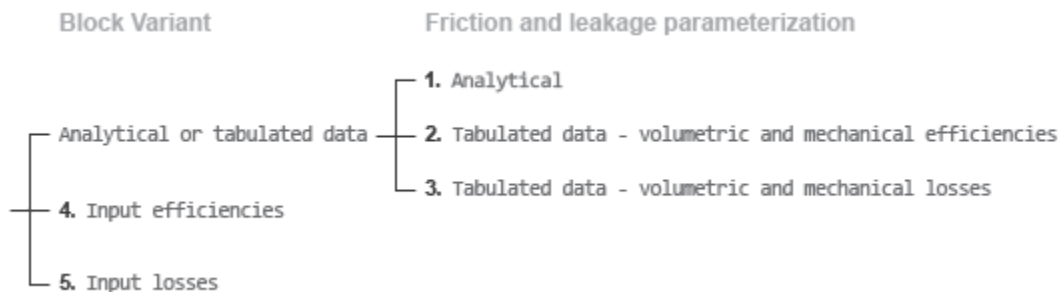
- Mode **1**: forward pump — A positive shaft angular velocity generates a positive pressure gain.
- Mode **2**: reverse motor — A negative pressure drop (shown in the figure as a positive pressure gain) generates a negative shaft angular velocity.
- Mode **3**: reverse pump — A negative shaft angular velocity generates a negative pressure gain.

- **Mode 4:** forward motor — A positive pressure drop (shown in the figure as a negative pressure gain) generates a positive shaft angular velocity.

The response time of the pump is considered negligible in comparison with the system response time. The pump is assumed to reach steady state nearly instantaneously and is treated as a quasi-steady component.

### Block Variants and Loss Parameterizations

The pump model accounts for power losses due to leakage and friction. Leakage is internal and occurs between the pump inlet and outlet only. The block computes the leakage flow rate and friction torque using your choice of five loss parameterizations. You select a parameterization using block variants and, in the **Analytical** or **tabulated data** case, the **Leakage and friction parameterization** parameter.



### Loss Parameterizations

The block provides three Simscape variants to select from. To change the active block variant, use the **Modeling option** parameter. The available variants are:

- **Analytical or tabulated data** — Obtain the mechanical and volumetric efficiencies or losses from analytical models based on nominal parameters or from tabulated data. Use the **Leakage and friction parameterization** parameter to select the exact input type.
- **Input efficiencies** — Provide the mechanical and volumetric efficiencies directly through physical signal input ports.
- **Input losses** — Provide the mechanical and volumetric losses directly through physical signal input ports. The mechanical loss is defined as the internal friction torque. The volumetric loss is defined as the internal leakage flow rate.

### Displacement Parameterizations

The displacement volume input depends on the block variant selected. If the active block variant is **Input efficiencies** or **Input losses**, the block obtains the instantaneous displacement volume directly from the physical signal input at port D.

If the active block variant is **Analytical** or **tabulated data**, the block computes the instantaneous displacement volume from the control member position specified at port C. This computation depends on the **Displacement parameterization** parameter setting:

- **Maximum displacement and control member stroke** — Compute the displacement volume per unit rotation as a linear function of the control member position specified at port C.

- **Displacement vs. control member position table** — Compute the displacement volume per unit volume using interpolation or extrapolation of displacement tabular data specified at discrete control member positions.

### Flow Rate and Driving Torque

The volumetric flow rate generated at the pump is

$$q = q_{\text{Ideal}} + q_{\text{Leak}},$$

where:

- $q$  is the net volumetric flow rate.
- $q_{\text{Ideal}}$  is the ideal volumetric flow rate.
- $q_{\text{Leak}}$  is the internal leakage volumetric flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{\text{Ideal}} + \tau_{\text{Friction}},$$

where:

- $\tau$  is the net driving torque.
- $\tau_{\text{Ideal}}$  is the ideal driving torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal volumetric flow rate is

$$q_{\text{Ideal}} = D_{\text{Sat}} \cdot \omega,$$

and the ideal driving torque is

$$\tau_{\text{Ideal}} = D_{\text{Sat}} \cdot \Delta p,$$

where:

- $D_{\text{Sat}}$  is a smoothed displacement computed so as to remove numerical discontinuities between negative and positive displacements.
- $\omega$  is the instantaneous angular velocity of the rotary shaft.
- $\Delta p$  is the instantaneous pressure gain from inlet to outlet.

### Saturation Displacement

The saturation displacement depends on the block variant selected. If the active variant is Analytical or tabulated data,

$$D_{\text{Sat}} = \begin{cases} \text{sign}(D) \cdot D_{\text{Max}}, & |D| \geq D_{\text{Max}} \\ \sqrt{D^2 + D_{\text{Threshold}}^2}, & D \geq 0 \\ -\sqrt{D^2 + D_{\text{Threshold}}^2}, & D < 0 \end{cases},$$

where:

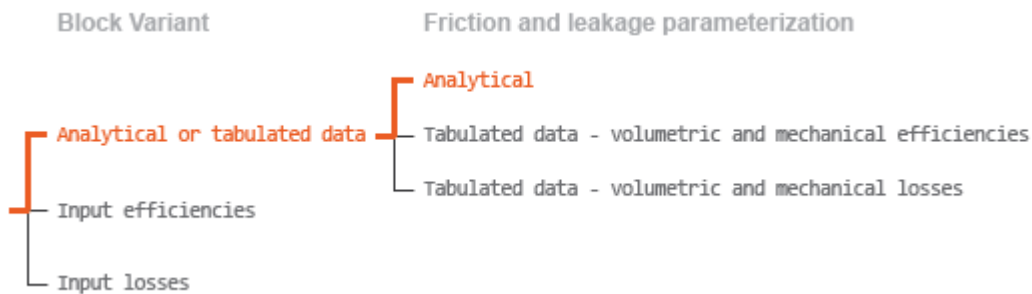
- $D$  is the instantaneous fluid displacement determined from the physical signal input specified at port **C** or port **D**.
- $D_{Max}$  is the specified value of the **Maximum displacement** block parameter.
- $D_{Threshold}$  is the specified value of the **Displacement threshold for pump-motor transition** block parameter.

If the active variant is `Input efficiencies` or `Input losses`, there is no upper bound on the displacement input and the saturation displacement reduces to:

$$D_{Sat} = \begin{cases} \sqrt{D^2 + D_{Thresh}^2}, & D \geq 0 \\ -\sqrt{D^2 + D_{Thresh}^2}, & D < 0 \end{cases}$$

### Leakage Flow Rate and Friction Torque

The internal leakage flow rate and friction torque calculations depend on the block variant selected. If the block variant is `Analytical` or `tabulated data`, the calculations depend also on the **Leakage and friction parameterization** parameter setting. There are five possible permutations of block variant and parameterization settings.



### Case 1: Analytical Efficiency Calculation

If the active block variant is `Analytical` or `tabulated data` and the **Leakage and friction parameterization** parameter is set to `Analytical`, the leakage flow rate is

$$q_{Leak} = K_{HP}\Delta p,$$

and the friction torque is

$$\tau_{Friction} = \left( \tau_0 + K_{TP} \left| \frac{D_{Sat}}{D_{Max}} \right| |\Delta p| \right) \tanh\left( \frac{4\omega}{\omega_{Threshold}} \right),$$

where:

- $K_{HP}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. This coefficient is computed from the specified nominal parameters.
- $K_{TP}$  is the specified value of the **Friction torque vs pressure gain coefficient** block parameter.
- $\tau_0$  is the specified value of the **No-load torque** block parameter.
- $\omega_{Threshold}$  is the threshold angular velocity for the motor-pump transition. The threshold angular velocity is an internally set fraction of the specified value of the **Nominal shaft angular velocity** block parameter.

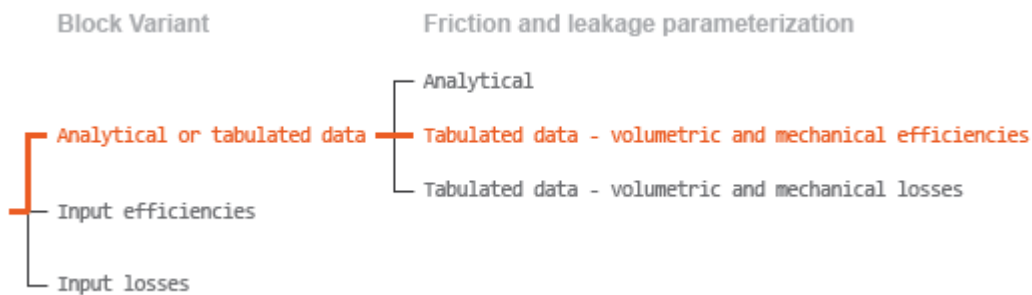


The Hagen-Poiseuille coefficient is determined from nominal fluid and component parameters through the equation

$$K_{HP} = \frac{\nu_{Nom}}{\rho v} \frac{\rho_{Nom} \omega_{Nom} D_{Max}}{\Delta p_{Nom}} (1 - \eta_{v,Nom}),$$

where:

- $\nu_{Nom}$  is the specified value of the **Nominal kinematic viscosity** block parameter. This is the kinematic viscosity at which the nominal volumetric efficiency is specified.
- $\rho_{Nom}$  is the specified value of the **Nominal fluid density** block parameter. This is the density at which the nominal volumetric efficiency is specified.
- $\omega_{Nom}$  is the specified value of the **Nominal shaft angular velocity** block parameter. This is the angular velocity at which the nominal volumetric efficiency is specified.
- $\rho$  is the actual fluid density in the attached hydraulic (isothermal liquid) network. This density can differ from the specified value of the **Nominal fluid density** block parameter.
- $v$  is the kinematic viscosity of the fluid associated with the fluid network.
- $\Delta p_{Nom}$  is the specified value of the **Nominal pressure gain** block parameter. This is the pressure drop at which the nominal volumetric efficiency is specified.
- $\eta_{v,Nom}$  is the specified value of the **Volumetric efficiency at nominal conditions** block parameter. This is the volumetric efficiency corresponding to the specified nominal conditions.



## Case 2: Efficiency Tabulated Data

If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies, the leakage flow rate is

$$q_{Leak} = q_{Leak,Pump} \frac{(1 + \alpha)}{2} + q_{Leak,Motor} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{Friction} = \tau_{Friction,Pump} \frac{1 + \alpha}{2} + \tau_{Friction,Motor} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $q_{Leak,Pump}$  is the leakage flow rate in pump mode.

- $q_{\text{Leak, Motor}}$  is the leakage flow rate in motor mode.
- $\tau_{\text{Friction, Pump}}$  is the friction torque in pump mode.
- $\tau_{\text{Friction, Motor}}$  is the friction torque in motor mode.

The smoothing parameter  $\alpha$  is given by the hyperbolic function

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4D}{D_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the specified value of the **Pressure drop threshold for motor-pump transition** block parameter.
- $\omega_{\text{Threshold}}$  is the specified value of the **Angular velocity threshold for motor-pump transition** block parameter.
- $D_{\text{Threshold}}$  is the specified value of the **Displacement threshold for motor-pump transition** block parameter.

The leakage flow rate is computed from efficiency tabulated data through the equation

$$q_{\text{Leak, Pump}} = (1 - \eta_v)q_{\text{Ideal}},$$

in pump mode and through the equation

$$q_{\text{Leak, Motor}} = -(1 - \eta_v)q,$$

in motor mode, where:

- $\eta_v$  is the volumetric efficiency obtained through interpolation or extrapolation of the **Volumetric efficiency table, e\_v(dp,w,D)** parameter data.

Similarly, the friction torque is computed from efficiency tabulated data through the equation

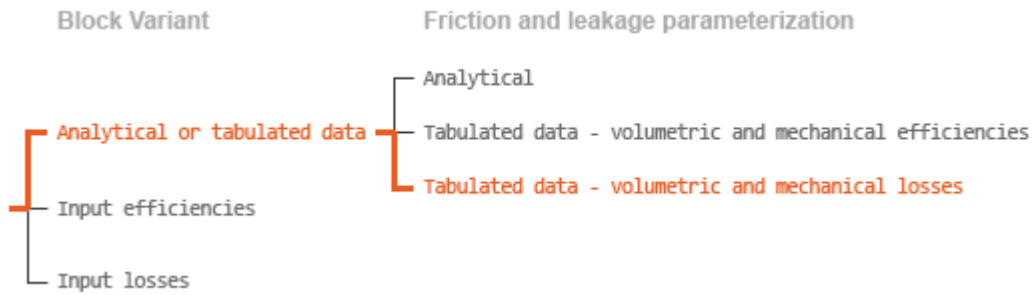
$$\tau_{\text{Friction, Pump}} = (1 - \eta_m)\tau,$$

in pump mode and through the equation

$$\tau_{\text{Friction, Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}},$$

in motor mode, where:

- $\eta_m$  is the mechanical efficiency obtained through interpolation or extrapolation of the **Mechanical efficiency table, e\_m(dp,w,D)** parameter data.



### Case 3: Loss Tabulated Data

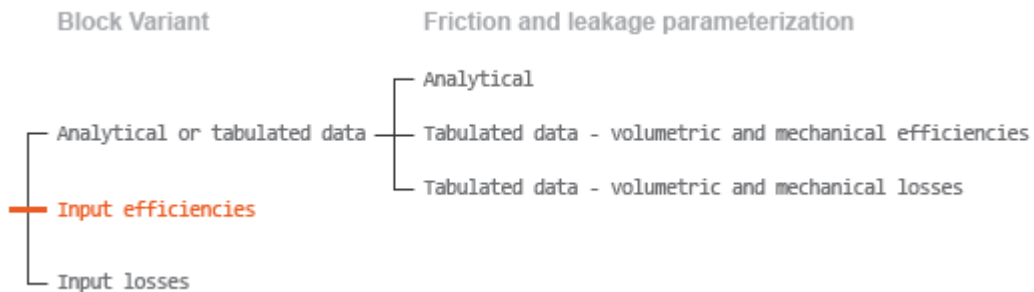
If the active block variant is Analytical or tabulated data and the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses, the leakage flow rate equation is

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega, D_{\text{Sat}}).$$

and the friction torque equation is

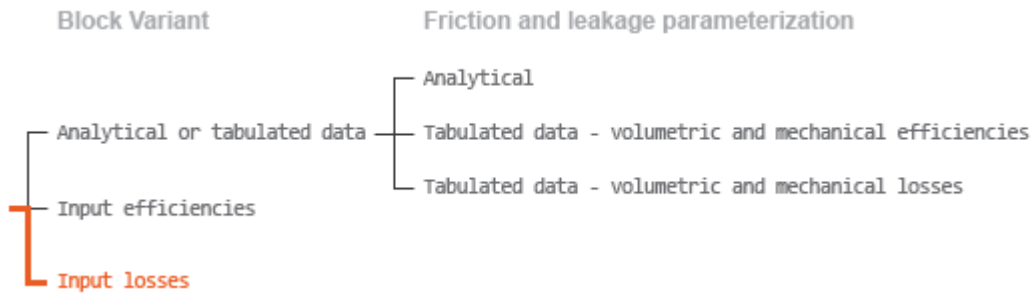
$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega, D_{\text{Sat}}),$$

where  $q_{\text{Leak}}(\Delta p, \omega, D_{\text{Sat}})$  and  $\tau_{\text{Friction}}(\Delta p, \omega, D_{\text{Sat}})$  are the volumetric and mechanical losses, obtained through interpolation or extrapolation of the **Volumetric loss table,  $q_{\text{loss}}(\text{dp}, \text{w}, \text{D})$**  and **Mechanical loss table, torque\_loss (dp,w,D)** parameter data.



### Case 4: Efficiency Physical Signal Inputs

If the active block variant is Input efficiencies, the leakage flow rate and friction torque calculations are as described for efficiency tabulated data (case 2). The volumetric and mechanical efficiency lookup tables are replaced with physical signal inputs that you specify through ports EV and EM.



### Case 5: Loss Physical Signal Inputs

If the block variant is `Input losses`, the leakage flow rate and friction torque calculations are as described for loss tabulated data (case 3). The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports `LV` and `LM`.

#### Assumptions

- Fluid compressibility is negligible.
- Loading on the pump shaft due to inertia, friction, and spring forces is negligible.

## Ports

### Input

#### **C – Control member offset, m**

physical signal

Physical signal input port for the control member position. The block maps the control member offset to the corresponding displacement volume using the tabulated data specified in the block dialog box.

#### Dependencies

This port is exposed only when the block variant is set to `Analytical` or `tabulated data`.

#### **D – Displacement volume, cm<sup>3</sup>/rev**

physical signal

Physical signal input port for the volume of fluid displaced per unit rotation. A smoothing function eases the transition between positive and negative input values.

#### Dependencies

This port is exposed only when the block variant is set to `Input efficiencies` or `Input losses`.

#### **EV – Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

**Dependencies**

This port is exposed only when the block variant is set to Input efficiencies.

**EM — Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

**Dependencies**

This port is exposed only when the block variant is set to Input efficiencies.

**LV — Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss, defined as the internal leakage flow rate between the pump inlets.

**Dependencies**

This port is exposed only when the block variant is set to Input losses.

**LM — Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss, defined as the friction torque on the rotating pump shaft.

**Dependencies**

This port is exposed only when the block variant is set to Input losses.

**Conserving****T — Pump inlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the pump inlet.

**P — Pump outlet**

hydraulic (isothermal liquid)

Hydraulic (isothermal liquid) conserving port representing the pump outlet.

**S — Pump shaft**

mechanical rotational

Mechanical rotational conserving port representing the pump shaft.

**Parameters**

The exposed block parameters depend on the active block variant. See “Block Variants and Loss Parameterizations” on page 1-2008.

**Modeling option — Loss parameterizations**

Analytical or tabulated data | Input efficiencies | Input losses

Set the variant for mechanical and volumetric efficiencies or losses for the block.

**Variant 1: Analytical or tabulated data****Displacement parameterization — Parameterization used to map control positions to displacements**

Maximum displacement and control member stroke (default)

Parameterization used to convert the physical signal at input port C to an instantaneous displacement:

- **Maximum displacement and control member stroke** — Compute the displacement as a linear function of the control position specified at port C.
- **Displacement vs. control member position table** — Obtain the displacement through interpolation or extrapolation of tabulated data specified over a range of control positions.

**Restricted Parameter**

This parameter is locked for editing when using the Simscape Restricted mode.

**Maximum stroke — Control position corresponding to maximum displacement**

0.005 m (default) | scalar with units of length

Control position corresponding to a maximum displacement. The physical signal input at port C saturates at this value. If the input rises higher, the block sets the control position to the maximum stroke.

**Maximum displacement — Maximum fluid volume swept per unit shaft rotation**30 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Maximum fluid volume swept per unit shaft rotation. The displacement reaches this value when the control position hits the maximum stroke.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Maximum displacement and control member stroke.

**Control member position vector — Control positions at which to specify displacement tabular data**[-0.0075, -0.0025, 0.0, 0.0025, 0.0075] m (default) | *M*-element vector with units of length

*M*-element vector of control positions at which to specify the instantaneous displacement. The vector size, *M*, must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Displacement vector — Displacement tabular data for the specified control positions**

`[-30.0, -19.0, 0.0, 19.0, 30.0]` cm<sup>3</sup>/rev (default) | *M*-element vector with units of volume/angle

*M*-element vector with the displacement tabular data for the specified control positions. The vector size, *M*, must match that of the **Control member position vector** parameter.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Interpolation method — Numerical technique used to determine displacements within the tabular data range**

Linear (default) | Smooth

Numerical technique used to map control position signals to displacements within the tabular data range. The interpolation method joins tabular data points using straight or curved line segments. Displacements within the range of the tabular data are assumed to lie on these segments.

- **Linear** — Join neighboring data points using straight line segments. Line slopes are generally discontinuous at the line segment end points.
- **Smooth** — Join neighboring data points using curved line segments generated with a modified Akima algorithm. Line slopes are continuous at the line segment end points.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Restricted Parameter**

This parameter is locked for editing when using the Simscape Restricted mode.

**Extrapolation method — Numerical technique used to determine displacements outside the tabular data range**

Linear (default) | Nearest

Numerical technique used to map control position signals to displacements outside the tabular data range. The extrapolation method extends the first and last tabular data points outward using horizontal or sloped straight line segments. Displacements outside the range of the tabular data are assumed to lie on these segments.

- **Linear** — Extend the tabular data using sloped straight line segments. The line slopes are computed from the first and last two tabular data points.
- **Nearest** — Extend the tabular data using horizontal straight line segments. The lines correspond to the displacements specified in the first and last tabular data points.

**Dependencies**

This parameter is enabled when the **Displacement parameterization** parameter is set to Displacement vs. control member position table.

**Restricted Parameter**

This parameter is locked for editing when using the Simscape Restricted mode.

**Leakage and friction parameterization – Parameterization used to compute leakage flow rate and friction torque**

Analytical (default) | Tabulated data – volumetric and mechanical efficiencies | Tabulated data – volumetric and mechanical losses

Parameterization used to compute flow-rate and torque losses due to internal leaks and friction. The Analytical parameterization relies on nominal parameters generally available from component data sheets. The remaining, tabular, options rely on lookup tables to map pressure drop, angular velocity, and displacement to component efficiencies or losses. The tabular options include:

- Tabulated data – volumetric and mechanical efficiencies
- Tabulated data – volumetric and mechanical losses

**Nominal shaft angular velocity – Shaft angular velocity at which to specify the volumetric efficiency**

188 rad/s (default) | scalar with units of angle/time

Angular velocity of the rotating shaft at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using simple linear functions, the leakage flow rate and friction torque.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal pressure gain – Pressure gain at which to specify the volumetric efficiency**

100e5 Pa (default)

Pressure gain from inlet to outlet at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal kinematic viscosity – Kinematic viscosity at which to specify the volumetric efficiency**

18 cSt (default) | scalar with units of area/time

Kinematic viscosity of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

**Nominal fluid density – Fluid density at which to specify the volumetric efficiency**

900 kg/m<sup>3</sup> (default) | scalar with units of mass/volume



Mass density of the hydraulic fluid at which the component's nominal volumetric efficiency is known. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

#### Volumetric efficiency at nominal conditions – Volumetric efficiency at the specified nominal conditions

0.92 (default) | unitless scalar between 0 and 1

Volumetric efficiency, defined as the ratio of actual to ideal volumetric flow rates, at the specified nominal conditions. Nominal parameters are typically published for standard operating conditions in manufacturer's data sheets. The block uses this parameter to calculate, using a simple linear function, the internal leakage flow rate.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

#### No-load torque – Minimum torque required to induce shaft rotation

0.05 N\*m (default) | scalar with units of torque

Torque required to overcome seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Analytical.

#### Friction torque vs. pressure gain coefficient at maximum displacement – Proportionality constant at maximum displacement between friction torque and pressure gain

0.6e-6 N\*m/Pa (default) | scalar with units of torque/pressure

Proportionality constant at maximum displacement between the friction torque on the mechanical shaft and the pressure gain from inlet to outlet.

#### Dependencies

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

#### Displacement threshold for pump–motor transition – Displacement at which to initiate the transition between pumping and motoring modes

0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between pumping and motoring modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

**Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

**Pressure gain vector for efficiencies,  $dp$  – Pressure gains at which to specify the volumetric and mechanical efficiencies** $M$ -element vector with units of pressure (default)

$M$ -element vector of pressure gains at which to specify the efficiency tabular data. The vector size,  $M$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Shaft angular velocity vector for efficiencies,  $w$  – Angular velocities at which to specify the volumetric and mechanical efficiencies** $N$ -element vector with units of angular velocity (default)

$N$ -element vector of shaft angular velocities at which to specify the efficiency tabular data. The vector size,  $N$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Displacement vector for efficiencies,  $D$  – Displacements at which to specify the volumetric and mechanical efficiencies** $L$ -element vector with units of volume/angle (default)

$L$ -element vector of displacements at which to specify the efficiency tabular data. The vector size,  $N$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

**Volumetric efficiency table,  $e_v(dp,w,D)$  – Volumetric efficiencies at the specified pressure gains, angular velocities, and displacements**unitless  $M$ -by- $N$ -by- $L$  matrix

$M$ -by- $N$ -by- $L$  matrix with the volumetric efficiencies at the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must fall in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector for efficiencies,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector for efficiencies,  $D$**  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w,D)$  – Mechanical efficiencies at the specified pressure drops, angular velocities, and displacements**unitless  $M$ -by- $N$  matrix

$M$ -by- $N$ -by- $L$  matrix with the mechanical efficiencies corresponding to the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must fall in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector for efficiencies,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector for efficiencies,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector for efficiencies,  $D$**  parameter.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between motor and pump modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Angular velocity threshold for pump–motor transition – Shaft angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies.

**Check if operating beyond the octants of supplied tabulated data – Simulation warning mode for operating conditions outside the range of tabulated data**

None (default) | Warning

Simulation warning mode for operating conditions outside the range of tabulated data. Select Warning to be notified when the fluid pressure gain, shaft angular velocity, or instantaneous displacement cross outside the specified tabular data. The warning does not cause simulation to stop.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical efficiencies or Tabulated data – volumetric and mechanical losses.

**Pressure gain vector for losses,  $dp$  – Pressure gains at which to specify the volumetric and mechanical losses**

$M$ -element vector with units of pressure (default)

$M$ -element vector of pressure gains at which to specify the loss tabular data. The vector size,  $M$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

**Shaft angular velocity vector for losses,  $w$  – Angular velocities at which to specify the volumetric and mechanical losses**

$N$ -element vector with units of angle/time (default)

$N$ -element vector of shaft angular velocities at which to specify the efficiency tabular data. The vector size,  $N$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must monotonically increase in value from left to right.

**Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

**Displacement vector for losses,  $D$  – Displacements at which to specify the volumetric and mechanical losses**

$L$ -element vector with units of volume/angle (default)

$L$ -element vector of displacements at which to specify the loss tabular data. The vector size,  $N$ , must be two or greater. The vector elements need not be uniformly spaced. However, they must be monotonically increasing or decreasing.

### **Volumetric loss table, $q_{\text{loss}}(dp,w,D)$ – Internal leakage flow rates at the specified pressure gains, angular velocities, and displacements**

*M-by-N-by-L* matrix with units of volume/time

*M-by-N-by-L* matrix with the volumetric gains at the specified fluid pressure drops, shaft angular velocities, and displacements. Volumetric loss is defined here as the internal leakage volumetric flow rate between port A and port B. *M*, *N*, and *L* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure gain vector for losses,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.
- *L* is the number of vector elements in the **Displacement vector for losses,  $D$**  parameter.

#### **Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

### **Mechanical loss table, $\text{torque}_{\text{loss}}(dp,w,D)$ – Friction torques at the specified pressure gains, angular velocities, and displacements**

*M-by-N-by-L* matrix with units of torque

*M-by-N-by-L* matrix with the mechanical losses at the specified fluid pressure gains, shaft angular velocities, and displacements. Mechanical loss is defined here as the friction torque due to seals and internal components. *M*, *N*, and *L* are the sizes of the specified lookup-table vectors:

- *M* is the number of vector elements in the **Pressure gain vector for losses,  $dp$**  parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector for losses,  $w$**  parameter.
- *L* is the number of vector elements in the **Displacement vector for losses,  $D$**  parameter.

#### **Dependencies**

This parameter is enabled when the **Leakage and friction parameterization** parameter is set to Tabulated data – volumetric and mechanical losses.

#### **Variant 2: Input efficiencies**

##### **Minimum volumetric efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal falls below the minimum volumetric efficiency, the volumetric efficiency is set to the minimum volumetric efficiency.

##### **Maximum volumetric efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the volumetric efficiency. The input from physical signal port EV saturates at the specified value. If the input signal rises above the maximum volumetric efficiency, the volumetric efficiency is set to the maximum volumetric efficiency.

**Minimum mechanical efficiency – Lower saturation bound on the volumetric efficiency input signal**

1e-3 (default) | unitless scalar between 0 and 1

Smallest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal falls below the minimum mechanical efficiency, the mechanical efficiency is set to the minimum mechanical efficiency.

**Maximum mechanical efficiency – Upper saturation bound on the volumetric efficiency input signal**

1 (default) | unitless scalar between 0 and 1

Largest allowed value of the mechanical efficiency. The input from physical signal port EM saturates at the specified value. If the input signal rises above the maximum mechanical efficiency, the mechanical efficiency is set to the maximum mechanical efficiency.

**Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between motor and pump modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Angular velocity threshold for pump–motor transition – Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Displacement threshold for motor-pump transition – Displacement at which to initiate a smooth transition between pump and motor modes**

0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

**Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

**Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

## Dependencies

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to Warning.

### Variant 3: Input losses

#### **Pressure gain threshold for pump–motor transition – Pressure gain at which to initiate a smooth transition between motor and pump modes**

1e5 Pa (default) | scalar with units of pressure

Pressure gain from inlet to outlet below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### **Angular velocity threshold for pump–motor transition – Angular velocity at which to initiate a smooth transition between pump and motor modes**

10 rad/s (default) | scalar with units of angle/time

Shaft angular velocity below which the component begins to transition between motoring and pumping modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### **Displacement threshold for pump–motor transition – Displacement below which the transition between pumping and motoring modes begins**

0.5 cm<sup>3</sup>/rev (default) | scalar with units of volume/angle

Absolute value of the instantaneous displacement below which the component transitions between pumping and motoring modes. A hyperbolic Tanh function transforms the leakage flow rate and friction torque such that the transition is continuous and smooth.

#### **Check if operating beyond the pump mode – Simulation warning mode for operating conditions outside pumping mode**

None (default) | Warning

Simulation warning mode for operating conditions outside the pumping mode. A warning is issued if the pump transitions to motoring mode. Select Warning to be notified when this transition occurs. The warning does not cause simulation to stop.

#### **Check if lower side pressure violating minimum valid condition – Simulation warning mode for minimum valid pressure**

None (default) | Warning

Simulation warning mode for invalid pressures at the component ports. Select Warning to be notified when pressure falls below a minimum specified value. The warning can be useful in models where pressure can fall below the saturated vapor pressure of the hydraulic fluid, causing cavitation to occur.

#### **Minimum valid pressure – Pressure required to trigger simulation warning**

0 (default) | scalar with units of pressure

Lower bound of the pressure validity range. A warning is issued if pressure falls below the specified value.

### **Dependencies**

This parameter is enabled when the **Check if lower side pressure violating minimum valid condition** parameter is set to *Warning*.

### **Extended Capabilities**

#### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

[Fixed-Displacement Pump](#) | [Fixed-Displacement Pump \(TL\)](#) | [Fixed-Displacement Motor](#) | [Variable-Displacement Motor](#) | [Fixed-Displacement Motor \(TL\)](#)

### **Topics**

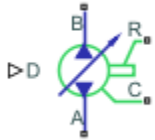
[“Upgrading Simscape Fluids Models Containing Hydraulics \(Isothermal\) Blocks”](#)



# Variable-Displacement Pump (IL)

Variable-displacement pump in an isothermal liquid network

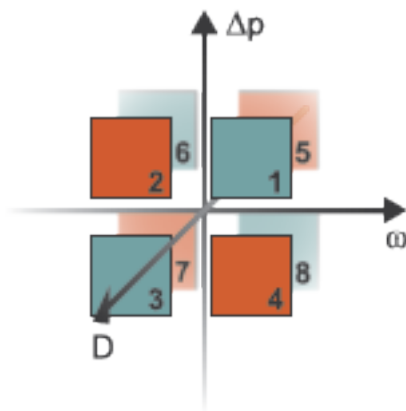
**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors



## Description

The Variable-Displacement Pump (IL) block models a pump with variable-volume displacement. The fluid may move from port **A** to port **B**, called *forward mode*, or from port **B** to port **A**, called *reverse mode*. Pump mode operation occurs when there is a pressure gain in the direction of the flow. Motor mode operation occurs when there is a pressure drop in the direction of the flow.

The shaft rotation corresponds to the sign of the fluid volume moving through the pump, which is received as a physical signal at port **D**. Positive fluid displacement at **D** corresponds to positive shaft rotation in forward mode. Negative fluid displacement at **D** corresponds to negative shaft angular velocity in forward mode.



## Operation Modes

The block has eight modes of operation. The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement at port **D**. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- Mode 1, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**.
- Mode 2, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.

- Mode 3, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.
- Mode 4, *Forward Motor*: Flow from port **A** to **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.
- Mode 5, *Reverse Motor*: Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.
- Mode 6, *Forward Pump*: Negative shaft angular velocity causes pressure increase from **A** to **B** and flow from **A** to **B**.
- Mode 7, *Forward Motor*: Flow from port **A** to **B** causes a pressure decrease from **A** to **B** and negative shaft angular velocity.
- Mode 8, *Reverse Pump*: Positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.

The pump block has analytical, lookup table, and physical signal parameterizations. When using tabulated data or an input signal for parameterization, you can choose to characterize pump operation based on efficiency or losses.

The threshold parameters **Pressure gain threshold for pump-motor transition**, **Angular velocity threshold for pump-motor transition**, and **Displacement threshold for pump-motor transition** identify regions where numerically smoothed flow transition between the pump operational modes can occur. For the pressure and angular velocity thresholds, choose a transition region that provides some margin for the transition term, but which is small enough relative to the typical pump pressure gain and angular velocity so that it will not impact calculation results. For the displacement threshold, choose a threshold value that is smaller than the typical displacement volume during normal operation.

### Analytical Leakage and Friction Parameterization

If you set **Leakage and friction parameterization** to `Analytical`, the block calculates internal leakage and shaft friction from constant nominal values of shaft velocity, pressure gain, volumetric displacement, and volumetric efficiency. The leakage flow rate, which is correlated with the pressure differential over the pump, is calculated as:

$$\dot{m}_{leak} = K\rho_{avg}\Delta p,$$

where:

- $\Delta p$  is  $p_B - p_A$ .
- $\rho_{avg}$  is the average fluid density.
- $K$  is the Hagen-Poiseuille coefficient for analytical loss,

$$K = \frac{D_{nom}\omega_{nom}(1 - \eta_{v, nom})}{\Delta p_{nom}},$$

where:

- $D_{nom}$  is the **Nominal displacement**.
- $\omega_{nom}$  is the **Nominal shaft angular velocity**.
- $\eta_{nom}$  is the **Volumetric efficiency at nominal conditions**.
- $\Delta p_{nom}$  is the **Nominal pressure gain**.

The friction torque, which is related to the pump pressure differential, is calculated as:

$$\tau_{fr} = \left( \tau_0 + k \left| \Delta p \frac{D}{D_{nom}} \right| \right) \tanh \left( \frac{4\omega}{5 \times 10^{-5} \omega_{nom}} \right),$$

where:

- $\tau_0$  is the **No-load torque**.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = \left( \frac{1 - \eta_{m,nom}}{\eta_{m,nom}} \right) D_{nom} \Delta p_{nom}.$$

- $\omega$  is the relative shaft angular velocity, or  $\omega_R - \omega_C$ .

### Tabulated Data Parameterizations

When using tabulated data for pump efficiencies or losses, you can provide data for one or more of the pump operational modes. The signs of the tabulated data determine the operational regime of the block. When data is provided for less than eight operational modes, the block calculates the complementing data for the other mode(s) by extending the given data into the remaining octants.

#### The Tabulated data - volumetric and mechanical efficiencies parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \dot{m}_{leak,pump} \left( \frac{1 + \alpha}{2} \right) + \dot{m}_{leak,motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\dot{m}_{leak,pump} = (1 - \eta_v) \dot{m}_{ideal}$
- $\dot{m}_{leak,motor} = (\eta_v - 1) \dot{m}$

and  $\eta_v$  is the volumetric efficiency, which is interpolated from the user-provided tabulated data. The transition term,  $\alpha$ , is

$$\alpha = \tanh \left( \frac{4\Delta p}{\Delta p_{threshold}} \right) \tanh \left( \frac{4\omega}{\omega_{threshold}} \right) \tanh \left( \frac{4D}{D_{threshold}} \right),$$

where:

- $\Delta p$  is  $p_B - p_A$ .
- $\Delta p_{threshold}$  is the **Pressure gain threshold for pump-motor transition**.
- $\omega$  is  $\omega_R - \omega_C$ .
- $\omega_{threshold}$  is the **Angular velocity threshold for pump-motor transition**.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{fr, pump} \left( \frac{1 + \alpha}{2} \right) + \tau_{fr, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\tau_{fr, pump} = (1 - \eta_m)\tau$
- $\tau_{fr, motor} = (\eta_m - 1)\tau_{ideal}$

and  $\eta_m$  is the mechanical efficiency, which is interpolated from the user-provided tabulated data.

### The Tabulated data - volumetric and mechanical losses parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{loss}(\Delta p, \omega, D),$$

where  $q_{loss}$  is interpolated from the **Volumetric loss table,  $q_{loss}(dp, w, D)$**  parameter, which is based on user-supplied data for pressure gain, shaft angular velocity, and fluid volumetric displacement.

The shaft friction torque is calculated as:

$$\tau_{fr} = \tau_{loss}(\Delta p, \omega, D),$$

where  $\tau_{loss}$  is interpolated from the **Mechanical loss table,  $torque\_loss(dp, w, D)$**  parameter, which is based on user-supplied data for pressure gain, shaft angular velocity, and fluid volumetric displacement.

### Input Signal Parameterization

When you select **Input signal - volumetric and mechanical efficiencies**, ports **EV** and **EM** are enabled. The internal leakage and shaft friction are calculated in the same way as the **Tabulated data - volumetric and mechanical efficiencies** parameterization, except that  $\eta_v$  and  $\eta_m$  are received directly at ports **EV** and **EM**, respectively.

When you select **Input signal - volumetric and mechanical losses**, ports **LV** and **LM** are enabled. These ports receive leakage flow and friction torque as positive physical signals. The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{LV} \tanh\left(\frac{4\Delta p}{p_{thresh}}\right),$$

where:

- $q_{LV}$  is the leakage flow received at port **LV**.
- $p_{thresh}$  is the **Pressure gain threshold for pump-motor transition** parameter.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{LM} \tanh\left(\frac{4\omega}{\omega_{thresh}}\right),$$

where

- $\tau_{LM}$  is the friction torque received at port **LM**.

- $\omega_{\text{thresh}}$  is the **Angular velocity threshold for pump-motor transition** parameter.

The volumetric and mechanical efficiencies range between the user-defined specified minimum and maximum values. Any values lower or higher than this range will take on the minimum and maximum specified values, respectively.

### Pump Operation

The pump flow rate is:

$$\dot{m} = \dot{m}_{\text{ideal}} - \dot{m}_{\text{leak}},$$

where  $\dot{m}_{\text{ideal}} = \rho_{\text{avg}} D \cdot \omega$ .

The pump torque is:

$$\tau = \tau_{\text{ideal}} + \tau_{fr},$$

where  $\tau_{\text{ideal}} = D \cdot \Delta p$ .

The mechanical power delivered by the pump shaft is:

$$\varphi_{\text{mech}} = \tau \omega,$$

and the pump hydraulic power is:

$$\varphi_{\text{hyd}} = \frac{\Delta p \dot{m}}{\rho_{\text{avg}}}.$$

To be notified if the block is operating beyond the supplied tabulated data, you can set **Check if operating beyond the octants of supplied tabulated data** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs. When using input signals for volumetric or mechanical losses, you can be notified if the simulation surpasses operating modes with the **Check if operating beyond pump mode** parameter.

You can also monitor pump functionality. Set **Check if pressures are less than pump minimum pressure** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs.

## Ports

### Conserving

#### A – Liquid port

isothermal liquid

Liquid entry or exit port to the pump.

#### B – Liquid port

isothermal liquid

Liquid entry or exit port to the pump.

#### R – Mechanical port

mechanical rotational

Rotating shaft angular velocity and torque.

**C – Mechanical port**

mechanical rotational

Pump casing reference angular velocity and torque.

**Input****D – Volumetric displacement, m<sup>3</sup>/rad**

physical signal

Volumetric displacement of the pump, in m<sup>3</sup>/rad, specified as a physical signal.

**EV – Volumetric efficiency**

physical signal

Pump efficiency for fluid displacement, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**EM – Mechanical efficiency**

physical signal

Pump efficiency for the mechanical delivery of power, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**LV – Leakage flow rate, m<sup>3</sup>/s**

physical signal

Pump volumetric losses, in m<sup>3</sup>/s, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**LM – Friction torque, N\*m**

physical signal

Pump mechanical losses in N\*m, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Parameters

### Leakage and friction parameterization — Method of calculating leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Parameterization of the leakage and friction characteristics of the pump.

- In the `Analytical` parameterization, the leakage flow rate and the friction torque are calculated by analytical equations.
- In the `Tabulated data - volumetric and mechanical efficiencies` parameterization, the volumetric and mechanical efficiencies are calculated from the user-supplied **Pressure gain vector,  $dp$** , **Shaft angular velocity vector,  $w$** , and **Displacement vector,  $D$**  parameters and interpolated from the 3-D dependent **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  tables.
- In the `Tabulated data - volumetric and mechanical loss` parameterization, the leakage flow rate and friction torque are calculated from the user-supplied **Pressure gain vector,  $dp$** ; **Shaft angular velocity vector,  $w$** ; and **Displacement vector,  $D$**  parameters and interpolated from the 3-D dependent **Volumetric loss table,  $q\_loss(dp,w,D)$**  and **Mechanical loss table,  $torque\_loss(dp,w,D)$**  tables.
- In the `Input signal - volumetric and mechanical efficiencies` parameterization, the volumetric and mechanical efficiencies are received as physical signals at ports **EV** and **EM**, respectively.
- In the `Input signal - volumetric and mechanical loss` parameterization, the leakage flow rate and friction torque are received as physical signals at ports **LV** and **LM**, respectively.

### Nominal displacement — Nominal fluid displacement

30 cm<sup>3</sup>/rev (default) | scalar

Amount of fluid displaced by shaft rotating under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to `Analytical`.

### Nominal shaft angular velocity — Shaft angular velocity

188 rad/s (default) | scalar

Angular velocity of the shaft under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to `Analytical`.

### Nominal pressure gain — Pressure drop between fluid entry and exit

10 MPa (default) | scalar

Pump pressure gain between the fluid entry and exit under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to `Analytical`.

**Volumetric efficiency at nominal conditions – Ratio of actual flow rate to ideal flow rate at nominal conditions**

0.92 (default) | positive scalar in the range of (0,1]

Ratio of actual flow rate to ideal flow rate at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Baseline torque**

0 N\*m (default) | scalar

Minimum value of torque to overcome seal friction and induce shaft motion.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of actual to ideal mechanical power**

0.88 (default) | positive scalar

Ratio of actual mechanical power to ideal mechanical power at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Pressure gain vector, dp – Vector of pressure data for tabulated data parameterization**

[.1, 1, 2] MPa (default) | 1-by-n vector

Vector of pressure differential values for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** and the **Displacement vector, D** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Shaft angular velocity vector, w – Vector of angular velocity data for tabulated data parameterization**

[25, 50, 100, 200, 300, 400] rad/s (default) | 1-by-n vector

Vector of angular velocity data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Pressure gain vector, dp** and the **Displacement vector, D** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:



- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Displacement vector,  $D$  – Vector of displacement volumes for tabulated data parameterization**

`[-30, -19, 19, 30]`  $\text{cm}^3/\text{s}$  (default) | 1-by- $n$  vector

Vector of fluid volumetric displacement data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector,  $w$**  and the **Pressure gain vector,  $dp$**  parameters for the 3-D dependent **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Volumetric efficiency table,  $e_v(dp,w,D)$  – Volumetric efficiency for tabulated data parameterization**

`repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4)` (default) |  $M$ -by- $N$ -by- $P$  matrix

$M$ -by- $N$ -by- $P$  matrix of volumetric efficiencies at the specified fluid pressure gain, shaft angular velocity, and volumetric displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w,D)$  – Mechanical efficiency for tabulated data parameterization**

`repmat([.996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984], 1, 1, 4)` (default) |  $M$ -by- $N$ -by- $P$  matrix

$M$ -by- $N$ -by- $P$  matrix of mechanical efficiencies at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric loss table,  $q\_loss(dp,w,D)$  — Volumetric losses for tabulated data parameterization**

```
repmat([.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125
, .108; .1079, .108, .11, .108, .1605, .18] * 1e-3, 1, 1, 4)m^3/s (default) |
numerical array
```

$M$ -by- $N$ -by- $P$  matrix of volumetric leakage at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Mechanical loss table,  $torque\_loss(dp,w,D)$  — Mechanical losses for tabulated data parameterization**

```
repmat([.002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556
, .0505; .1937, .1937, .1833, .1833, .1729, .1626], 1, 1, 4) N*m (default) |
numerical array
```

$M$ -by- $N$ -by- $P$  matrix of friction torque at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical loss.

**Minimum volumetric efficiency — Minimum value of volumetric efficiency**

```
1e-3 (default) | positive scalar in the range of (0,1]
```

Minimum value of volumetric efficiency. If the input signal is below this value, the volumetric efficiency is set to the minimum volumetric efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum volumetric efficiency – Maximum value of volumetric efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of volumetric efficiency. If the input signal is above this value, the volumetric efficiency is set to the maximum volumetric efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Minimum mechanical efficiency – Minimum value of mechanical efficiency**

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of mechanical efficiency. If the input signal is below this value, the mechanical efficiency is set to the minimum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency – Maximum value of mechanical efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of mechanical efficiency. If the input signal is above this value, the mechanical efficiency is set to the maximum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure gain threshold for pump-motor transition – Pressure threshold for mode transition**

1e-3 MPa (default) | positive scalar

Pump pressure gain that indicates the transition threshold between pump and motor functionality. A transition region is defined around 0 MPa between the positive and negative values of the pressure gain threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Angular velocity threshold for pump-motor transition – Angular velocity threshold for mode transition**

10 rad/s (default) | positive scalar

Shaft angular velocity that indicates the transition threshold between motor and pump functionality. A transition region is defined around 0 rad/s between the positive and negative values of the angular

velocity threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical loss

**Displacement threshold for pump-motor transition — Displacement threshold for mode transition**

0.1 cm<sup>3</sup>/s (default) | positive scalar

Volumetric displacement that indicates the transition threshold between pump and motor functionality. A transition region is defined around 0 cm<sup>3</sup>/s between the positive and negative values of the displacement threshold. Within this transition region, the computed leakage flow rate and friction torque is adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other. It is also used to transition the ideal mass flow rate when the sign of **D** changes.

**Check if operating beyond the octants of supplied tabulated data — Whether to notify if extents of supplied data are surpassed**

None (default) | Warning | Error

Whether to notify if the extents of the supplied data are surpassed. Select Warning to be notified when the block uses values beyond the supplied data range. Select Error to stop the simulation when the block uses values beyond the supplied data range.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating beyond pump mode — Whether to notify if block operates outside of the pump mode functionality**

None (default) | Warning | Error

Whether to notify if the block operates outside of the pump mode functionality. Select Warning to be notified when the block operates in the forward or reverse motor modes. Select Error to stop the simulation when the block operates in the forward or reverse motor modes.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Check if pressures are less than pump minimum pressure — Whether to notify if fluid exit pressure is low**

None (default) | Warning | Error

Whether to notify if the fluid at port **A** and **B** experiences low pressure. Select **Warning** to be notified when the pressure falls below a minimum specified value. Select **Error** to stop the simulation when the pressure falls below a minimum specified value.

The parameter helps identify potential conditions for cavitation, when the fluid pressure falls below the fluid vapor pressure.

**Pump minimum pressure — Lower threshold of acceptable pressure at the pump outlet**

0.101325 MPa (default) | positive scalar

Lower threshold of acceptable pressure at the pump inlet or outlet.

**Dependencies**

To enable this parameter, set **Check if pressures are less than pump minimum pressure** to either:

- Warning
- Error

## Version History

Introduced in R2020a

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

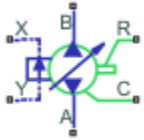
## See Also

Variable-Displacement Pump (TL) | Fixed-Displacement Pump (IL) | Pressure-Compensated Pump (IL) | Centrifugal Pump (IL) | Variable-Displacement Motor (IL)

## Pressure-Compensated Pump (IL)

Constant-pressure, variable-displacement pump in an isothermal liquid network

**Library:** Simscape / Fluids / Isothermal Liquid / Pumps & Motors

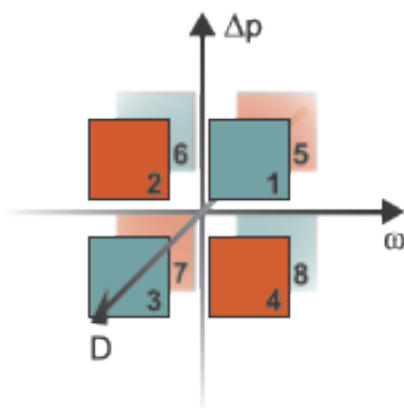


### Description

The Pressure-Compensated Pump (IL) block models a constant-pressure, variable-displacement pump in an isothermal liquid network. The pump displacement is controlled by the differential pressure,  $p_{control}$ , measured between ports **X** and **Y**. When this pressure exceeds the **Set pressure differential**, the fluid displacement is adjusted according to the pump **Leakage and friction parameterization**. The variable-displacement functionality occurs within the **Pressure regulation range** between the **Maximum displacement**, at  $p_{set}$ , and the **Minimum displacement**, at  $p_{max}$ .

The fluid may move from port **A** to port **B**, called *forward mode*, or from port **B** to port **A**, called *reverse mode*. Pump mode operation occurs when there is a pressure gain in the direction of the flow. Motor mode operation occurs when there is a pressure drop in the direction of the flow.

Shaft rotation corresponds to the sign of the fluid volume moving through the pump. Positive fluid displacement corresponds to positive shaft rotation in forward mode. Negative fluid displacement corresponds to negative shaft angular velocity in forward mode.



### Operation Modes

The block has eight modes of operation. The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement, set by the pressure differential. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- Mode 1, *Forward Pump*: Positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**.
- Mode 2, *Reverse Motor* : Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- Mode 3, *Reverse Pump*: Negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.
- Mode 4, *Forward Motor*: Flow from port **A** to **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.
- Mode 5, *Reverse Motor* : Flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.
- Mode 6, *Forward Pump*: Negative shaft angular velocity causes pressure increase from **A** to **B** and flow from **A** to **B**.
- Mode 7, *Forward Motor*: Flow from port **A** to **B** causes a pressure decrease from **A** to **B** and negative shaft angular velocity.
- Mode 8, *Reverse Pump*: Positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from **B** to **A**.

The block has analytical, lookup table, and physical signal parameterizations. When using tabulated data or an input signal for parameterization, you can choose to characterize pump operation based on efficiency or losses.

The threshold parameters **Pressure gain threshold for pump-motor transition**, **Angular velocity threshold for pump-motor transition**, and **Displacement threshold for pump-motor transition** identify regions where numerically smoothed flow transition between the pump operational modes can occur. For the pressure and angular velocity thresholds, choose a transition region that provides some margin for the transition term, but which is small enough relative to the typical pump pressure gain and angular velocity so that it will not impact calculation results. For the displacement threshold, choose a threshold value that is smaller than the typical displacement volume during normal operation.

### Analytical Leakage and Friction Parameterization

If you set **Leakage and friction parameterization** to *Analytical*, the block calculates leakage and friction from constant values for shaft velocity, pressure gain, and torque. The leakage flow rate, which is correlated with the pressure differential over the pump, is calculated as:

$$\dot{m}_{leak} = K\rho_{avg}\Delta p,$$

where:

- $\Delta p_{nom}$  is  $p_B - p_A$ .
- $\rho_{avg}$  is the average fluid density.
- $K$  is the Hagen-Poiseuille coefficient for analytical loss,

$$K = \frac{D_{nom}\omega_{nom}(1 - \eta_{v, nom})}{\Delta p_{nom}},$$

where:

- $D_{nom}$  is the **Nominal displacement**.

- $\omega_{nom}$  is the **Nominal shaft angular velocity**.
- $\eta_{nom}$  is the **Volumetric efficiency at nominal conditions**.
- $\Delta p_{nom}$  is the **Nominal pressure gain**.

The friction torque, which is related to the pump pressure differential, is calculated as:

$$\tau_{fr} = \left( \tau_0 + k \left| \Delta p \frac{D}{D_{nom}} \right| \right) \tanh \left( \frac{4\omega}{5 \times 10^{-5} \omega_{nom}} \right),$$

where:

- $\tau_0$  is the **No-load torque**.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which is determined from the **Mechanical efficiency at nominal conditions**,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = \left( \frac{1 - \eta_{m,nom}}{\eta_{m,nom}} \right) D_{nom} \Delta p_{nom}.$$

- $\omega$  is the relative shaft angular velocity, or  $\omega_R - \omega_C$ .

### Tabulated Data Parameterizations

When using tabulated data for pump efficiencies or losses, you can provide data for one or more of the pump operational modes. The signs of the tabulated data determine the operational regime of the block. When data is provided for less than eight operational modes, the block calculates the complementing data for the other mode(s) by extending the given data into the remaining octants.

#### The Tabulated data - volumetric and mechanical efficiencies parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \dot{m}_{leak,pump} \left( \frac{1 + \alpha}{2} \right) + \dot{m}_{leak,motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\dot{m}_{leak,pump} = (1 - \eta_v) \dot{m}_{ideal}$
- $\dot{m}_{leak,motor} = (\eta_v - 1) \dot{m}$

and  $\eta_v$  is the volumetric efficiency, which is interpolated from the user-provided tabulated data. The transition term,  $\alpha$ , is

$$\alpha = \tanh \left( \frac{4\Delta p}{\Delta p_{threshold}} \right) \tanh \left( \frac{4\omega}{\omega_{threshold}} \right) \tanh \left( \frac{4D}{D_{threshold}} \right),$$

where:

- $\Delta p$  is  $p_B - p_A$ .



- $p_{\text{threshold}}$  is the **Pressure gain threshold for pump-motor transition**.
- $\omega$  is  $\omega_R - \omega_C$ .
- $\omega_{\text{threshold}}$  is the **Angular velocity threshold for pump-motor transition**.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{fr, pump} \left( \frac{1 + \alpha}{2} \right) + \tau_{fr, motor} \left( \frac{1 - \alpha}{2} \right),$$

where:

- $\tau_{fr, pump} = (1 - \eta_m)\tau$
- $\tau_{fr, motor} = (\eta_m - 1)\tau_{ideal}$

and  $\eta_m$  is the mechanical efficiency, which is interpolated from the user-provided tabulated data.

#### The Tabulated data - volumetric and mechanical losses parameterization

The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{loss}(\Delta p, \omega, D),$$

where  $q_{loss}$  is interpolated from the **Volumetric loss table,  $q_{loss}(dp, w, D)$**  parameter, which is based on user-supplied data for pressure gain, shaft angular velocity, and fluid volumetric displacement.

The shaft friction torque is calculated as:

$$\tau_{fr} = \tau_{loss}(\Delta p, \omega, D),$$

where  $\tau_{loss}$  is interpolated from the **Mechanical loss table, torque\_loss(dp, w, D)** parameter, which is based on user-supplied data for pressure gain, shaft angular velocity, and fluid volumetric displacement.

#### Input Signal Parameterization

When you select Input signal - volumetric and mechanical efficiencies, ports **EV** and **EM** are enabled. The internal leakage and shaft friction are calculated in the same way as the Tabulated data - volumetric and mechanical efficiencies parameterization, except that  $\eta_v$  and  $\eta_m$  are received directly at ports **EV** and **EM**, respectively.

When you select Input signal - volumetric and mechanical losses, ports **LV** and **LM** are enabled. These ports receive leakage flow and friction torque as positive physical signals. The leakage flow rate is calculated as:

$$\dot{m}_{leak} = \rho_{avg} q_{LV} \tanh\left(\frac{4\Delta p}{p_{thresh}}\right),$$

where:

- $q_{LV}$  is the leakage flow received at port **LV**.
- $p_{thresh}$  is the **Pressure gain threshold for pump-motor transition** parameter.

The friction torque is calculated as:

$$\tau_{fr} = \tau_{LM} \tanh\left(\frac{4\omega}{\omega_{thresh}}\right),$$

where

- $\tau_{LM}$  is the friction torque received at port **LM**.
- $\omega_{thresh}$  is the **Angular velocity threshold for pump-motor transition** parameter.

The volumetric and mechanical efficiencies range between the user-defined specified minimum and maximum values. Any values lower or higher than this range will take on the minimum and maximum specified values, respectively.

### Pump Operation

The pump flow rate is:

$$\dot{m} = \dot{m}_{ideal} - \dot{m}_{leak},$$

where  $\dot{m}_{ideal} = \rho_{avg} D \cdot \omega$ .

The pump torque is:

$$\tau = \tau_{ideal} + \tau_{fr},$$

where  $\tau_{ideal} = D \cdot \Delta p$ .

The mechanical power delivered by the pump shaft is:

$$\varphi_{mech} = \tau\omega,$$

and the pump hydraulic power is:

$$\varphi_{hyd} = \frac{\Delta p \dot{m}}{\rho_{avg}}.$$

To be notified if the block is operating beyond the supplied tabulated data, set **Check if operating beyond the octants of supplied tabulated data** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs. For parameterization by input signal for volumetric or mechanical losses, you can be notified if the simulation surpasses operating modes with the **Check if operating beyond pump mode** parameter.

You can also monitor pump functionality. Set **Check if pressures are less than pump minimum pressure** to Warning to receive a warning if this occurs, or Error to stop the simulation when this occurs.

### Displacement Parameterization

The linear parameterization of the pump displacement is:

$$D = \hat{p}(D_{min} - D_{max}) + D_{max},$$

where the normalized pressure,  $\hat{p}$ , is

$$\hat{p} = \frac{p_{control} - p_{set}}{p_{max} - p_{set}}.$$

where  $p_{max}$  is the sum of the **Set pressure differential** and the **Pressure regulation range**.

### Displacement Dynamics

If displacement dynamics are modeled, a lag is introduced to the flow response to the modeled control pressure.  $p_{control}$  becomes the dynamic control pressure,  $p_{dyn}$ ; otherwise,  $p_{control}$  is the steady-state pressure. The instantaneous change in dynamic control pressure is calculated based on the **Time constant**,  $\tau$ :

$$\dot{p}_{dyn} = \frac{p_{control} - p_{dyn}}{\tau}.$$

By default, **Displacement dynamics** is set to Off.

### Numerically-Smoothed Pressure

At the extremes of the control pressure range, you can maintain numerical robustness in your simulation by adjusting the block **Smoothing factor**. A smoothing function is applied to every calculated control pressure, but primarily influences the simulation at the extremes of this range.

The **Smoothing factor**,  $s$ , is applied to the normalized pressure,  $\hat{p}$ :

$$\hat{p}_{smoothed} = \frac{1}{2} + \frac{1}{2} \sqrt{\hat{p}^2 + \left(\frac{s}{4}\right)^2} - \frac{1}{2} \sqrt{(\hat{p} - 1)^2 + \left(\frac{s}{4}\right)^2}.$$

and the smoothed pressure is:

$$p_{smoothed} = \hat{p}_{smoothed}(p_{max} - p_{set}) + p_{set}.$$

## Ports

### Conserving

#### A — Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the pump.

#### B — Liquid port

isothermal liquid

Entry or exit port of the liquid to or from the pump.

#### X — Pressure reference $P_x$ , MPa

isothermal liquid

Control pressure in units of MPa, denoted  $P_x$ . The control pressure,  $P_x - P_y$ , is compared against the **Set pressure differential** to trigger or moderate variable pump displacement.

#### Y — Pressure reference $P_y$ , MPa

isothermal liquid

Control pressure in units of MPa, denoted  $P_y$ . The control pressure,  $P_x - P_y$ , is compared against the **Set pressure differential** to trigger or moderate variable pump displacement.

**R – Mechanical port**

mechanical rotational

Rotating shaft angular velocity and torque.

**C – Mechanical port**

mechanical rotational

Pump casing reference angular velocity and torque.

**EV – Volumetric efficiency**

physical signal

Pump efficiency for fluid displacement, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**EM – Mechanical efficiency**

physical signal

Pump efficiency for the mechanical supply of energy, specified as a physical signal. The value must be between 0 and 1.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**LV – Leakage flow rate, m<sup>3</sup>/s**

physical signal

Pump losses associated with fluid displacement in m<sup>3</sup>/s, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**LM – Friction torque, N\*m**

physical signal

Pump losses associated with the mechanical supply of energy in N\*m, specified as a physical signal.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

## Parameters

### Pump

#### Leakage and friction parameterization — Method of calculating leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Parameterization of the leakage and friction characteristics of the pump.

- In the **Analytical** parameterization, the leakage flow rate and the friction torque are calculated by analytical equations.
- In the **Tabulated data - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are calculated from the user-supplied **Pressure gain vector,  $dp$** , **Shaft angular velocity vector,  $w$** , and **Displacement vector,  $D$**  parameters and interpolated from the 3-D **Volumetric efficiency table,  $e_v(dp,w,D)$**  and **Mechanical efficiency table,  $e_m(dp,w,D)$**  tables.
- In the **Tabulated data - volumetric and mechanical losses** parameterization, the leakage flow rate and friction torque are calculated from the user-supplied **Pressure gain vector,  $dp$** , **Shaft angular velocity vector,  $w$** , and **Displacement vector,  $D$**  parameters and interpolated from the 3-D **Volumetric loss table,  $q\_loss(dp,w,D)$**  and **Mechanical loss table,  $torque\_loss(dp,w,D)$**  parameters.
- In the **Input signal - volumetric and mechanical efficiencies** parameterization, the volumetric and mechanical efficiencies are received as physical signals at ports **EV** and **EM**, respectively.
- In the **Input signal - volumetric and mechanical loss** parameterization, the leakage flow rate and friction torque are received as physical signals at ports **LV** and **LM**, respectively.

#### Nominal displacement — Fixed-volume fluid displacement

30 cm<sup>3</sup>/rev (default) | scalar

Amount of fluid displaced by shaft rotating under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

#### Nominal shaft angular velocity — Shaft angular velocity

188 rad/s (default) | scalar

Angular velocity of the shaft under nominal operating conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

#### Nominal pressure gain — Pressure gain between fluid entry and exit

10 MPa (default) | scalar

Pump pressure gain between the fluid entry and exit under nominal operating conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Volumetric efficiency at nominal conditions – Ratio of actual flow rate to ideal flow rate**

0.92 (default) | positive scalar in the range of (0,1]

Ratio of actual flow rate to ideal flow rate at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**No-load torque – Baseline torque**

0 N\*m (default) | scalar

Minimum value of torque to overcome seal friction and induce shaft motion.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Mechanical efficiency at nominal conditions – Ratio of actual to ideal mechanical power**

0.88 (default) | positive scalar

Ratio of actual mechanical power to ideal mechanical power at nominal conditions.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

**Pressure gain vector, dp – Vector of pressure data for tabulated data parameterization**

[.1, 1, 2] MPa (default) | 1-by-*n* vector

Vector of pressure differential values for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** and the **Displacement vector, D** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Shaft angular velocity vector, w – Vector of angular velocity data for tabulated data parameterization**

[25, 50, 100, 200, 300, 400] rad/s (default) | 1-by-*n* vector

Vector of angular velocity data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Pressure gain vector, dp** and the **Displacement vector, D** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Displacement vector, D – Vector of displacement volumes for tabulated data parameterization**

`[-30, -19, 19, 30]` cm<sup>3</sup>/s (default) | 1-by-*n* vector

Vector of fluid volumetric displacement data for the tabular parameterization of leakage and torque friction. This vector forms an independent axis with the **Shaft angular velocity vector, w** and the **Pressure gain vector, dp** parameters for the 3-D dependent **Volumetric efficiency table, e\_v(dp,w,D)** and **Mechanical efficiency table, e\_m(dp,w,D)** parameters. The vector elements must be listed in ascending order.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Volumetric efficiency table, e\_v(dp,w,D) – Volumetric efficiency for tabulated data parameterization**

`repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4)` (default) | *M*-by-*N*-by-*P* matrix

*M*-by-*N*-by-*P* matrix of volumetric efficiencies at the specified fluid pressure gain, shaft angular velocity, and volumetric displacement. Linear interpolation is employed between table elements. *M*, *N*, and *P* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Pressure gain vector, dp** parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector, w** parameter.
- *P* is the number of vector elements in the **Displacement vector, D** parameter.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table, e\_m(dp,w,D) – Mechanical efficiency for tabulated data parameterization**

`repmat([.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984], 1, 1, 4)` (default) | *M*-by-*N*-by-*P* matrix

*M*-by-*N*-by-*P* matrix of mechanical efficiencies at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements. *M*, *N*, and *P* are the sizes of the corresponding vectors:

- *M* is the number of vector elements in the **Pressure gain vector, dp** parameter.
- *N* is the number of vector elements in the **Shaft angular velocity vector, w** parameter.

- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Volumetric loss table, $q\_loss(dp,w,D)$ — Volumetric losses for tabulated data parameterization

```
repmat([.023, .023, .023, .023, .0285, .032; .0844, .0842, .0845, .084, .1125
, .108; .1079, .108, .11, .108, .1605, .18] * 1e-3, 1, 1, 4)m^3/s (default) |
numerical array
```

$M$ -by- $N$ -by- $P$  matrix of volumetric leakage at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical loss.

#### Mechanical loss table, $torque\_loss(dp,w,D)$ — Mechanical losses for tabulated data parameterization

```
repmat([.002, .002, .002, .002, .002, .002; .0607, .0556, .0556, .0556, .0556
, .0505; .1937, .1937, .1833, .1833, .1729, .1626], 1, 1, 4) N*m (default) |
numerical array
```

$M$ -by- $N$ -by- $P$  matrix of friction torque at the specified fluid pressure gain, shaft angular velocity, and displacement. Linear interpolation is employed between table elements.  $M$ ,  $N$ , and  $P$  are the sizes of the corresponding vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $P$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical loss.

#### Minimum volumetric efficiency — Minimum value of volumetric efficiency

```
1e-3 (default) | positive scalar in the range of (0,1]
```

Minimum value of volumetric efficiency. If the input signal is below this value, the volumetric efficiency is set to the minimum volumetric efficiency.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.



**Maximum volumetric efficiency – Maximum value of volumetric efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of volumetric efficiency. If the input signal is above this value, the volumetric efficiency is set to the maximum volumetric efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Minimum mechanical efficiency – Minimum value of mechanical efficiency**

1e-3 (default) | positive scalar in the range of (0,1]

Minimum value of mechanical efficiency. If the input signal is below this value, the mechanical efficiency is set to the minimum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency – Maximum value of mechanical efficiency**

1 (default) | positive scalar in the range of (0,1]

Maximum value of mechanical efficiency. If the input signal is above this value, the mechanical efficiency is set to the maximum mechanical efficiency.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure gain threshold for pump-motor transition – Pressure threshold for mode transition**

1e-3 MPa (default) | positive scalar

Threshold pressure gain value for the transition between pump and motor functionality. A transition region is defined around 0 MPa between the positive and negative values of the pressure gain threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to either:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical losses

**Angular velocity threshold for pump-motor transition – Angular velocity threshold for mode transition**

10 rad/s (default) | positive scalar

Threshold angular velocity value for the transition between motor and pump functionality. A transition region is defined around 0 rad/s between the positive and negative values of the angular

velocity threshold. Within this transition region, the computed leakage flow rate and friction torque are adjusted according to the transition term  $\alpha$  to ensure smooth transition from one mode to the other.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical efficiencies
- Input signal - volumetric and mechanical loss

**Check if operating beyond the octants of supplied tabulated data – Whether to notify if extents of supplied data are surpassed**

None (default) | Warning | Error

Whether to notify if the extents of the supplied data are surpassed. Select Warning to be notified when the block uses values beyond the supplied data range. Select Error to stop the simulation when the block uses values beyond the supplied data range.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating beyond pump mode – Whether to notify if block operates outside of the pump mode functionality**

None (default) | Warning | Error

Whether to notify if block operates outside of the pump mode functionality. Select Warning to be notified when the block operates in the forward or reverse motor modes. Select Error to stop the simulation when the block operates in the forward or reverse motor modes.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Check if pressures are less than pump minimum pressure – Whether to notify if fluid exit pressure is low**

None (default) | Warning | Error

Whether to notify if the fluid at port **A** or **B** experiences low pressure. Select Warning to be notified when the outlet pressure falls below a minimum specified value. Select Error to stop the simulation when the outlet pressure falls below a minimum specified value.

The parameter helps to identify potential conditions for cavitation, when the fluid pressure falls below the fluid vapor pressure.

**Pump minimum pressure – Lower threshold of acceptable pressure at the pump outlet**

0.101325 MPa (default) | positive scalar

Lower threshold of acceptable pressure at the pump inlet or outlet.

**Dependencies**

To enable this parameter, set **Check if pressures are less than pump minimum pressure** to:

- Warning
- Error

**Pressure Compensation****Maximum displacement — Upper limit to pump displacement**

30 cm<sup>3</sup>/rev (default) | scalar

Upper limit to pump displacement.

**Minimum displacement — Lower limit to pump displacement**

0.1 cm<sup>3</sup>/rev (default) | scalar

Lower limit to pump displacement.

**Set pressure differential — Threshold value for variable-displacement functionality**

10 MPa (default) | positive scalar

Threshold value beyond which pump displacement is adjusted.

**Pressure regulation range — Variable-displacement operational range**

0.6 MPa (default) | positive scalar

Variable-displacement operational range. The pump operates between the **Set pressure differential** and the pump maximum pressure, which is  $p_{set} + p_{regulation}$ .

**Displacement dynamics — Whether to account for flow response to displacement changes**

Off (default) | On

Whether to account for transient effects to the fluid system due to changes in pump fluid displacement. Setting **Displacement dynamics** to On approximates the condition change by introducing a first-order lag in the flow response. The magnitude of the **Time constant** also impacts the modeled displacement dynamics.

**Time constant — Flow response time constant**

0.1 s (default) | positive scalar

Constant that captures the time required for the fluid to reach steady-state when changing the fluid displacement. This parameter impacts the modeled displacement dynamics.

**Version History**

Introduced in R2020a

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Variable-Displacement Pump (IL) | Fixed-Displacement Pump (IL) | Centrifugal Pump (IL) | Jet Pump (IL)

# Variable-Displacement Pump (TL)

Variable-displacement bidirectional thermal liquid pump

**Library:** Simscape / Fluids / Thermal Liquid / Pumps & Motors



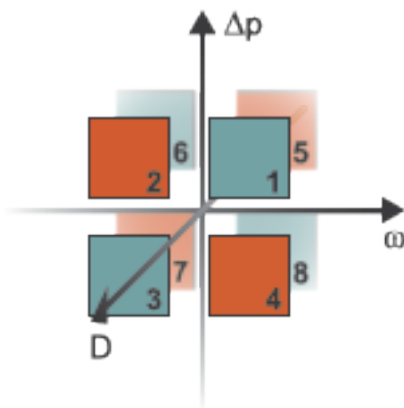
## Description

The Variable-Displacement Pump block represents a device that extracts power from a mechanical rotational network and delivers it to a thermal liquid network. The pump displacement varies during simulation according to the physical input signal at port **D**.

Ports **A** and **B** represent the pump inlets. Ports **R** and **C** represent the drive shaft and case. During normal operation, the pressure gain from port **A** to port **B** is positive if the angular velocity at port **R** relative to port **C** is positive.

## Operating Modes

The block has four modes of operation, as shown by this image.



The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement at port **D**. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- The quadrant labeled **1** represents the forward pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**
- The quadrant labeled **2** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- The quadrant labeled **3** represents the reverse pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**

- The quadrant labeled **4** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.
- The quadrant labeled **5** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.
- The quadrant labeled **6** represents the forward pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**.
- The quadrant labeled **7** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and negative shaft angular velocity.
- The quadrant labeled **8** represents the reverse pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**.

The response time of the pump is negligible in comparison with the system response time. The pump reaches steady state nearly instantaneously and is treated as a quasi-steady component.

### Energy Balance

The block associates the mechanical work done by the pump with an energy exchange. The governing energy balance equation is:

$$\phi_A + \phi_B + P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are the energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is the pump hydraulic power, which is a function of the pressure difference between the pump ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$ .

The block generates mechanical power due to torque,  $\tau$ , and angular velocity,  $\omega$ :

$$P_{mech} = \tau\omega.$$

### Flow Rate and Driving Torque

The mass flow rate generated at the pump is

$$\dot{m} = \dot{m}_{Ideal} - \dot{m}_{Leak},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{Ideal}$  is the ideal mass flow rate.
- $\dot{m}_{Leak}$  is the internal leakage mass flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{Ideal} + \tau_{Friction},$$

where:

- $\tau$  is the actual driving torque.
- $\tau_{Ideal}$  is the ideal driving torque.

- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal mass flow rate is

$$\dot{m}_{\text{Ideal}} = \rho D \omega,$$

and the ideal required torque is

$$\tau_{\text{Ideal}} = D \Delta p,$$

where:

- $\rho$  is the average of the fluid densities at thermal liquid ports **A** and **B**.
- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure gain from inlet to outlet.
- $D$  is the **Displacement** specified at physical signal port **D**.

### Leakage and friction parameterization

You can parameterize leakage and friction analytically, by using tabulated efficiencies or losses, or by using input efficiencies or input losses.

#### Analytical

When you set the **Leakage and Friction Parameterization** parameter to `Analytical`, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}} \rho_{\text{Avg}} \Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}} |\Delta p| \frac{|D|}{D_{\text{Nom}}} \tanh \frac{4\omega}{(5e - 5)\omega_{\text{Nom}}} \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. The block computes this coefficient from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the fluid, which is the average of the values at the ports.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which the block determines from the **Mechanical efficiency at nominal conditions** parameter,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr,nom} = \left( \frac{1 - \eta_{m,nom}}{\eta_{m,nom}} \right) D_{nom} \Delta p_{nom}.$$

- $\Delta p_{\text{Nom}}$  is the value of the **Nominal pressure gain** parameter. This value is the pressure gain at which the nominal volumetric efficiency is specified.

- $D_{\text{Nom}}$  is the value of the **Nominal Displacement** parameter.
- $\tau_0$  is the value of the **No-load torque** parameter.
- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter.

The block determines the Hagen-Poiseuille coefficient from the nominal fluid and component parameters

$$K_{\text{HP}} = \frac{D_{\text{Nom}}\omega_{\text{Nom}}\mu_{\text{Nom}}(1 - \eta_{v,\text{Nom}})}{\Delta p_{\text{Nom}}},$$

where:

- $\omega_{\text{Nom}}$  is the value of the **Nominal shaft angular velocity** parameter. This value is the angular velocity at which the block specifies the nominal volumetric efficiency.
- $\mu_{\text{Nom}}$  is the value of the **Nominal Dynamic viscosity** parameter. This value is the dynamic viscosity at which the block specifies the nominal volumetric efficiency.
- $\eta_{v,\text{Nom}}$  is the value of the **Volumetric efficiency at nominal conditions** parameter. This is the volumetric efficiency that corresponds to the specified nominal conditions.

#### Tabulated Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Tabulated data** - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \dot{m}_{\text{Leak,Pump}} \frac{(1 + \alpha)}{2} + \dot{m}_{\text{Leak,Motor}} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{\text{Friction}} = \tau_{\text{Friction,Pump}} \frac{1 + \alpha}{2} + \tau_{\text{Friction,Motor}} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{\text{Leak,Motor}}$  is the leakage flow rate in motor mode.
- $\dot{m}_{\text{Leak,Pump}}$  is the leakage flow rate in pump mode.
- $\tau_{\text{Friction,Motor}}$  is the friction torque in motor mode.
- $\tau_{\text{Friction,Pump}}$  is the friction torque in pump mode.

This hyperbolic function describes the smoothing parameter  $\alpha$

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{\text{Threshold}}}\right) \cdot \tanh\left(\frac{4D}{D_{\text{Threshold}}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the value of the **Pressure gain threshold for pump-motor transition** block parameter.
- $\omega_{\text{Threshold}}$  is the value of the **Angular velocity threshold for pump-motor transition** block parameter.



- $D_{\text{Threshold}}$  is the value of the **Angular velocity threshold for motor-pump transition** block parameter.

The block calculates the leakage flow rate from the volumetric efficiency, which the **Volumetric efficiency table** parameter specifies over the  $\Delta p$ - $\omega$ - $D$  domain. When operating in pump mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = (1 - \eta_v)\dot{m}_{\text{Ideal}},$$

where  $\eta_v$  is the volumetric efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = -(1 - \eta_v)\dot{m}.$$

The block calculates the friction torque from the mechanical efficiency, which the **Mechanical efficiency table** parameter specifies over the  $\Delta p$ - $\omega$ - $D$  domain. When operating in pump mode, the friction torque is

$$\tau_{\text{Friction,Pump}} = (1 - \eta_m)\tau,$$

where  $\eta_m$  is the mechanical efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the friction torque is

$$\tau_{\text{Friction,Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}}.$$

### Tabulated Losses

When you set the **Leakage and friction parameterization** parameter to **Tabulated data - volumetric and mechanical losses**, the block specifies the leakage volumetric flow rate in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega, D).$$

The block calculates the mass flow rate due to leakage from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The block calculates the friction torque in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega, D),$$

where  $q_{\text{Leak}}(\Delta p, \omega, D)$  and  $\tau_{\text{Friction}}(\Delta p, \omega, D)$  are the volumetric and mechanical losses, specified through interpolation or extrapolation of the tabulated data in the **Volumetric loss table** and **Mechanical loss table** parameters.

### Input Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical efficiencies** setting. The block replaces the volumetric and mechanical efficiency lookup tables with the physical signal input ports **EV** and **EM**.

The efficiencies are positive quantities with values between 0 and 1. The block sets input values outside of these bounds are to 0 for inputs smaller than 0 or 1 for inputs greater than 1. The block saturates the efficiency signals at the value of the **Minimum volumetric efficiency** or **Minimum**

**mechanical efficiency** parameter and the **Maximum volumetric efficiency** or **Maximum mechanical efficiency** parameter.

### Input Losses

When you set the **Leakage and friction parameterization** parameter to `Input signal - volumetric and mechanical losses`, the leakage flow rate and friction torque calculations are identical to the `Tabulated data - volumetric and mechanical efficiencies` setting. The block replaces the volumetric and mechanical loss lookup tables with the physical signal input ports **LV** and **LM**.

The block expects the inputs to be positive and sets the signs automatically from the  $\Delta p$ - $\omega$  quadrant where the component is operating. If you provide a negative signal, the block returns zero losses.

### Assumptions and Limitations

- The block treats the pump as a quasi-steady component.
- The block ignores the effects of fluid inertia and elevation.
- The pump wall is rigid.
- The block ignores external leakage.

## Ports

### Input

#### **D — Displacement volume, cm<sup>3</sup>/rev**

physical signal

Physical signal input port for the volume of fluid displaced rotation. A smoothing function eases the transition between positive and negative input values.

#### **EV — Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

### Dependencies

To enable this port, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical efficiencies`.

#### **EM — Mechanical efficiency, unitless**

physical signal

Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

### Dependencies

To enable this port, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical efficiencies`.

**LV – Volumetric loss, m<sup>3</sup>/s**

physical signal

Physical signal input port for the volumetric loss which is the internal leakage flow rate between the pump inlets.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**LM – Mechanical loss, N\*m**

physical signal

Physical signal input port for the mechanical loss which is the friction torque on the rotating pump shaft.

**Dependencies**

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Conserving****A – Pump inlet**

thermal liquid

Thermal liquid conserving port associated with the pump inlet.

**B – Pump outlet**

thermal liquid

Thermal liquid conserving port associated with the pump outlet.

**C – Pump case**

mechanical rotational

Mechanical rotational conserving port associated with the pump case.

**R – Pump shaft**

mechanical rotational

Mechanical rotational conserving port associated with the rotational pump shaft.

**Parameters****Leakage and friction parameterization – Parameterization of leakage flow rate and friction torque**

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute the flow-rate and torque losses due to internal leaks and friction. Use the Analytical if the block parameters are generally available from component data sheets. When you select Tabulated data - volumetric and mechanical efficiencies or Tabulated data

- volumetric and mechanical losses, the block uses lookup tables to map pressure gain, angular velocity, and displacement to component efficiencies or losses.

When you select **Input signal - volumetric and mechanical efficiencies** or **Input signal - volumetric and mechanical losses**, the block performs the leakage flow rate and friction torque calculations the same as the **Tabulated data - volumetric and mechanical efficiencies** or **Tabulated data - volumetric and mechanical losses** settings, respectively. When you select **Input signal - volumetric and mechanical efficiencies**, the block enables the **EV** and **EM** ports. You use these ports to specify the volumetric and mechanical efficiency. When you select **Input signal - volumetric and mechanical losses**, the block enables the **LV** and **LM** ports. You use these ports to specify the volumetric and mechanical losses.

**Nominal displacement — Displacement at which to specify volumetric efficiency**

30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid displacement for a given volumetric efficiency. These values are typically available at standard operating conditions in the manufacturer data sheet. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Nominal shaft angular velocity — Shaft angular velocity for given volumetric efficiency**

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

**Nominal pressure gain — Pressure gain for corresponding volumetric efficiency**

10 MPa (default) | scalar

Pressure gain that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

**Nominal dynamic viscosity — Dynamic viscosity at which to specify the volumetric efficiency**

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to **Analytical**.

**Volumetric efficiency at nominal conditions — Volumetric efficiency at specified nominal conditions**

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Mechanical efficiency at nominal conditions – Ratio of ideal-to-actual mechanical power

0.88 (default) | positive scalar

Ratio of ideal mechanical power to actual mechanical power at nominal conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### No-load torque – Minimum torque required to induce shaft rotation

0 N\*m (default) | scalar

Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Pressure gain vector, $dp$ – Pressure gains for given volumetric and mechanical efficiencies or losses

[.1, 1, 2] MPa (default) | vector

Pressure gains for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

#### Shaft angular velocity vector, $w$ – Angular velocities at which to specify volumetric and mechanical efficiencies or losses

[25, 50, 100, 200, 300, 400] rad/s (default) | vector

Shaft angular velocities for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Displacement vector, D — Displacements at which to specify volumetric and mechanical efficiencies or losses**

`[-30, -19, 19, 30] cm3/rev (default)`

Displacements at which to specify the efficiencies or losses tabular data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Volumetric efficiency table, e\_v(dp,w,D) — Volumetric efficiencies for given pressure gains, angular velocities, and displacements**

`repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4) (default) | matrix`

Volumetric efficiencies at the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must be in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector, dp** parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector, w** parameter.
- $L$  is the number of vector elements in the **Displacement vector, D** parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table, e\_m(dp,w,D) — Mechanical efficiencies for given pressure gains, angular velocities, and displacements**

`repmat([.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99; .981, .981, .982, .982, .983, .984], 1, 1, 4) (default) | matrix`

Mechanical efficiencies that correspond to the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must be in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector, dp** parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector, w** parameter.

- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

#### Volumetric loss table, $q\_loss(dp,w,D)$ – Internal leakage flow rates for corresponding pressure gains, angular velocities, and displacements

```
repmat([.0282, .0253, .0241, .0235, .0291, .0325; .2596, .1271, .1017, .0917, .1216, .1142; .7874, .1901, .141, .1211, .1797, .1978] * 1e-3, 1, 1, 4) m^3/s (default) | matrix
```

Volumetric losses at the specified fluid pressure gains, shaft angular velocities, and displacements. The block defines volumetric loss as the internal leakage volumetric flow rate between port **A** and port **B**.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

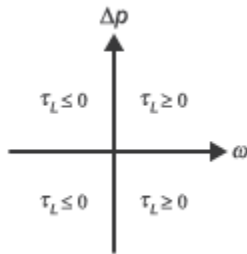
#### Mechanical loss table, $torque\_loss(dp,w,D)$ – Friction torques for corresponding pressure gains, angular velocities, and displacements

```
repmat([.002, .002, .002, .002, .002, .002; .06, .055, .055, .055, .055, .05; .19, .19, .18, .18, .17, .16], 1, 1, 4) N*m (default) | matrix
```

Mechanical losses for the given pressure gains, shaft angular velocities, and displacements. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2055 for the operation modes corresponding to parameter specifications and the resulting octants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

### Minimum volumetric efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum volumetric efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Minimum mechanical efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

### Maximum mechanical efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)



Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Pressure gain threshold for motor-pump transition — Pressure gain at which to initiate smooth transition between motor and pump modes

1e-3 MPa (default) | scalar

Pressure gain from the inlet to the outlet below which the block begins to transition between the motor and pump modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

#### Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate smooth transition between pump and motor modes

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between the motor and pump modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

#### Cross-sectional area at ports A and B — Flow area at component inlet and outlet

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

#### Check if operating beyond the quadrants of supplied tabulated data — Simulation warning mode for operating conditions outside range of tabulated data

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the range of tabulated data. If you select **Warning**, the block generates a warning when the fluid pressure gain or the shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the range of tabulated data.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating outside of pump mode — Simulation warning mode for operating conditions outside pump mode**

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the pump mode. When you set this parameter to **Warning**, the block generates a warning if the pump transitions to motoring mode. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the pump mode.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

**Version History**

Introduced in R2017b

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

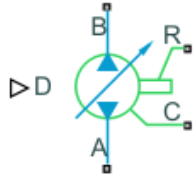
**See Also**

Centrifugal Pump (TL) | Fixed-Displacement Motor (TL) | Variable-Displacement Pump (TL)

## Variable-Displacement Pump (2P)

Variable-displacement bidirectional two-phase fluid pump

**Library:** Simscape / Fluids / Two-Phase Fluid / Fluid Machines



### Description

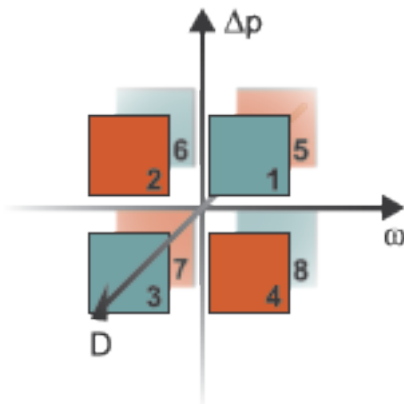
The Variable-Displacement Pump (2P) block represents a device that extracts power from a mechanical rotational network and delivers it to a two-phase fluid network. The pump displacement varies during simulation according to the physical input signal at port **D**.

Ports **A** and **B** represent the pump inlets. Ports **R** and **C** represent the drive shaft and case. During normal operation, the pressure gain from port **A** to port **B** is positive if the angular velocity at port **R** relative to port **C** is positive.

The Variable-Displacement Pump (2P) block assumes that liquid enters the pump inlet. You can use the **Report when fluid is not fully liquid** parameter to choose what the block does when the fluid does not meet liquid conditions. To move vapor in a two-phase fluid network, use a compressor.

### Operating Modes

The block has four modes of operation, as shown by this image.



The working mode depends on the pressure gain from port **A** to port **B**,  $\Delta p = p_B - p_A$ ; the angular velocity,  $\omega = \omega_R - \omega_C$ ; and the fluid volumetric displacement at port **D**. The figure above maps these modes to the octants of a  $\Delta p$ - $\omega$ - $D$  chart:

- The quadrant labeled **1** represents the forward pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**

- The quadrant labeled **2** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and negative shaft angular velocity.
- The quadrant labeled **3** represents the reverse pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**.
- The quadrant labeled **4** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and positive shaft angular velocity.
- The quadrant labeled **5** represents the reverse motor mode. In this mode, the flow from port **B** to port **A** causes a pressure decrease from **B** to **A** and positive shaft angular velocity.
- The quadrant labeled **6** represents the forward pump mode. In this mode, the negative shaft angular velocity causes a pressure increase from port **A** to port **B** and flow from port **A** to port **B**.
- The quadrant labeled **7** represents the forward motor mode. In this mode, the flow from port **A** to port **B** causes a pressure decrease from **A** to **B** and negative shaft angular velocity.
- The quadrant labeled **8** represents the reverse pump mode. In this mode, the positive shaft angular velocity causes a pressure increase from port **B** to port **A** and flow from port **B** to port **A**.

The response time of the pump is negligible in comparison with the system response time. The pump reaches steady state nearly instantaneously and is treated as a quasi-steady component.

### Energy Balance

The block associates the mechanical work done by the pump with an energy exchange. The governing energy balance equation is:

$$\phi_A + \phi_B + P_{hydro} = 0,$$

where:

- $\Phi_A$  and  $\Phi_B$  are the energy flow rates at ports **A** and **B**, respectively.
- $P_{hydro}$  is the pump hydraulic power, which is a function of the pressure difference between the pump ports:  $P_{hydro} = \Delta p \frac{\dot{m}}{\rho}$ .

The block generates mechanical power due to torque,  $\tau$ , and angular velocity,  $\omega$ :

$$P_{mech} = \tau\omega .$$

### Flow Rate and Driving Torque

The mass flow rate generated at the pump is

$$\dot{m} = \dot{m}_{Ideal} - \dot{m}_{Leak},$$

where:

- $\dot{m}$  is the actual mass flow rate.
- $\dot{m}_{Ideal}$  is the ideal mass flow rate.
- $\dot{m}_{Leak}$  is the internal leakage mass flow rate.

The driving torque required to power the pump is

$$\tau = \tau_{Ideal} + \tau_{Friction},$$

where:

- $\tau$  is the actual driving torque.
- $\tau_{\text{Ideal}}$  is the ideal driving torque.
- $\tau_{\text{Friction}}$  is the friction torque.

### Ideal Flow Rate and Ideal Torque

The ideal mass flow rate is

$$\dot{m}_{\text{Ideal}} = \rho D \omega,$$

and the ideal required torque is

$$\tau_{\text{Ideal}} = D \Delta p,$$

where:

- $\rho$  is the average of the fluid densities at ports **A** and **B**.
- $\omega$  is the shaft angular velocity.
- $\Delta p$  is the pressure gain from inlet to outlet.
- $D$  is the **Displacement** specified at physical signal port **D**.

### Leakage and friction parameterization

You can parameterize leakage and friction analytically, by using tabulated efficiencies or losses, or by using input efficiencies or input losses.

#### Analytical

When you set the **Leakage and Friction Parameterization** parameter to **Analytical**, the leakage flow rate is

$$\dot{m}_{\text{Leak}} = \frac{K_{\text{HP}} \rho_{\text{Avg}} \Delta p}{\mu_{\text{Avg}}},$$

and the friction torque is

$$\tau_{\text{Friction}} = \left( \tau_0 + K_{\text{TP}} |\Delta p| \frac{|D|}{D_{\text{Nom}}} \tanh \frac{4\omega}{(5e - 5)\omega_{\text{Nom}}} \right),$$

where:

- $K_{\text{HP}}$  is the Hagen-Poiseuille coefficient for laminar pipe flows. The block computes this coefficient from the specified nominal parameters.
- $\mu$  is the dynamic viscosity of the fluid, which is the average of the values at the ports.
- $k$  is the friction torque vs. pressure gain coefficient at nominal displacement, which the block determines from the **Mechanical efficiency at nominal conditions** parameter,  $\eta_{m,nom}$ :

$$k = \frac{\tau_{fr,nom} - \tau_0}{\Delta p_{nom}}.$$

$\tau_{fr,nom}$  is the friction torque at nominal conditions:

$$\tau_{fr, nom} = \left( \frac{1 - \eta_{m, nom}}{\eta_{m, nom}} \right) D_{nom} \Delta p_{nom}.$$

- $\Delta p_{Nom}$  is the value of the **Nominal pressure gain** parameter. This value is the pressure gain at which the nominal volumetric efficiency is specified.
- $D_{Nom}$  is the value of the **Nominal Displacement** parameter.
- $\tau_0$  is the value of the **No-load torque** parameter.
- $\omega_{Nom}$  is the value of the **Nominal shaft angular velocity** parameter.

The block determines the Hagen-Poiseuille coefficient from the nominal fluid and component parameters

$$K_{HP} = \frac{D_{Nom} \omega_{Nom} \mu_{Nom} (1 - \eta_{v, Nom})}{\Delta p_{Nom}},$$

where:

- $\omega_{Nom}$  is the value of the **Nominal shaft angular velocity** parameter. This value is the angular velocity at which the block specifies the nominal volumetric efficiency.
- $\mu_{Nom}$  is the value of the **Nominal Dynamic viscosity** parameter. This value is the dynamic viscosity at which the block specifies the nominal volumetric efficiency.
- $\eta_{v, Nom}$  is the value of the **Volumetric efficiency at nominal conditions** parameter. This is the volumetric efficiency that corresponds to the specified nominal conditions.

### Tabulated Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Tabulated data** - volumetric and mechanical efficiencies, the leakage flow rate is

$$\dot{m}_{Leak} = \dot{m}_{Leak, Pump} \frac{(1 + \alpha)}{2} + \dot{m}_{Leak, Motor} \frac{(1 - \alpha)}{2},$$

and the friction torque is

$$\tau_{Friction} = \tau_{Friction, Pump} \frac{1 + \alpha}{2} + \tau_{Friction, Motor} \frac{1 - \alpha}{2},$$

where:

- $\alpha$  is a numerical smoothing parameter for the motor-pump transition.
- $\dot{m}_{Leak, Motor}$  is the leakage flow rate in motor mode.
- $\dot{m}_{Leak, Pump}$  is the leakage flow rate in pump mode.
- $\tau_{Friction, Motor}$  is the friction torque in motor mode.
- $\tau_{Friction, Pump}$  is the friction torque in pump mode.

This hyperbolic function describes the smoothing parameter  $\alpha$

$$\alpha = \tanh\left(\frac{4\Delta p}{\Delta p_{Threshold}}\right) \cdot \tanh\left(\frac{4\omega}{\omega_{Threshold}}\right) \cdot \tanh\left(\frac{4D}{D_{Threshold}}\right),$$

where:

- $\Delta p_{\text{Threshold}}$  is the value of the **Pressure gain threshold for pump-motor transition** block parameter.
- $\omega_{\text{Threshold}}$  is the value of the **Angular velocity threshold for pump-motor transition** block parameter.
- $D_{\text{Threshold}}$  is the value of the **Angular velocity threshold for motor-pump transition** block parameter.

The block calculates the leakage flow rate from the volumetric efficiency, which the **Volumetric efficiency table** parameter specifies over the  $\Delta p$ - $\omega$ - $D$  domain. When operating in pump mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Pump}} = (1 - \eta_v)\dot{m}_{\text{Ideal}},$$

where  $\eta_v$  is the volumetric efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the leakage flow rate is:

$$\dot{m}_{\text{Leak,Motor}} = -(1 - \eta_v)\dot{m}.$$

The block calculates the friction torque from the mechanical efficiency, which the **Mechanical efficiency table** parameter specifies over the  $\Delta p$ - $\omega$ - $D$  domain. When operating in pump mode, the friction torque is

$$\tau_{\text{Friction,Pump}} = (1 - \eta_m)\tau,$$

where  $\eta_m$  is the mechanical efficiency, which the block obtains either by interpolation or extrapolation of the tabulated data. Similarly, when operating in motor mode, the friction torque is

$$\tau_{\text{Friction,Motor}} = -(1 - \eta_m)\tau_{\text{Ideal}}.$$

### Tabulated Losses

When you set the **Leakage and friction parameterization** parameter to **Tabulated data - volumetric and mechanical losses**, the block specifies the leakage volumetric flow rate in tabulated form over the  $\Delta p$ - $\omega$ - $D$  domain:

$$q_{\text{Leak}} = q_{\text{Leak}}(\Delta p, \omega, D).$$

The block calculates the mass flow rate due to leakage from the volumetric flow rate:

$$\dot{m}_{\text{Leak}} = \rho q_{\text{Leak}}.$$

The block calculates the friction torque in tabulated form:

$$\tau_{\text{Friction}} = \tau_{\text{Friction}}(\Delta p, \omega, D),$$

where  $q_{\text{Leak}}(\Delta p, \omega, D)$  and  $\tau_{\text{Friction}}(\Delta p, \omega, D)$  are the volumetric and mechanical losses, specified through interpolation or extrapolation of the tabulated data in the **Volumetric loss table** and **Mechanical loss table** parameters.

### Input Efficiencies

When you set the **Leakage and friction parameterization** parameter to **Input signal - volumetric and mechanical efficiencies**, the leakage flow rate and friction torque calculations are identical to the **Tabulated data - volumetric and mechanical**

efficiencies setting. The block replaces the volumetric and mechanical efficiency lookup tables with the physical signal input ports **EV** and **EM**.

When you set the **Leakage and friction parameterization** parameter to `Input signal - volumetric and mechanical losses`, the leakage flow rate and friction torque calculations are identical to the `Tabulated data - volumetric and mechanical efficiencies` setting. The block replaces the volumetric and mechanical loss lookup tables with the physical signal input ports **LV** and **LM**.

### **Input Losses**

When you set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical efficiencies`, the leakage flow rate and friction torque calculations are identical to the `Tabulated data - volumetric and mechanical efficiencies` setting. The volumetric and mechanical loss lookup tables are replaced with physical signal inputs that you specify through ports **LV** and **LM**.

The block expects the inputs to be positive and sets the signs automatically from the  $\Delta p$ - $\omega$  quadrant where the component is operating. If you provide a negative signal, the block returns zero losses.

### **Assumptions and Limitations**

- The block treats the pump as a quasi-steady component.
- The block ignores the effects of fluid inertia and elevation.
- The pump wall is rigid.
- The block ignores external leakage.

## **Ports**

### **Input**

#### **D — Displacement volume, cm<sup>3</sup>/rev**

physical signal

Physical signal input port for the volume of fluid displaced rotation. A smoothing function eases the transition between positive and negative input values.

#### **EV — Volumetric efficiency, unitless**

physical signal

Physical signal input port for the volumetric efficiency coefficient. The input signal has an upper bound at the **Maximum volumetric efficiency** parameter value and a lower bound at the **Minimum volumetric efficiency** parameter value.

### **Dependencies**

To enable this port, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical efficiencies`.

#### **EM — Mechanical efficiency, unitless**

physical signal



Physical signal input port for the mechanical efficiency coefficient. The input signal has an upper bound at the **Maximum mechanical efficiency** parameter value and a lower bound at the **Minimum mechanical efficiency** parameter value.

#### Dependencies

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### LV — Volumetric loss, $m^3/s$

physical signal

Physical signal input port for the volumetric loss which is the internal leakage flow rate between the pump inlets.

#### Dependencies

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

#### LM — Mechanical loss, $N*m$

physical signal

Physical signal input port for the mechanical loss which is the friction torque on the rotating pump shaft.

#### Dependencies

To enable this port, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical losses.

#### Conserving

##### A — Pump inlet

two-phase fluid

Two-phase fluid conserving port associated with the pump inlet.

##### B — Pump outlet

two-phase fluid

Two-phase fluid conserving port associated with the pump outlet.

##### C — Pump case

mechanical rotational

Mechanical rotational conserving port associated with the pump case.

##### R — Pump shaft

mechanical rotational

Mechanical rotational conserving port associated with the rotational pump shaft.

## Parameters

### Leakage and friction parameterization — Parameterization of leakage flow rate and friction torque

Analytical (default) | Tabulated data - volumetric and mechanical efficiencies | Tabulated data - volumetric and mechanical losses | Input signal - volumetric and mechanical efficiencies | Input signal - volumetric and mechanical losses

Method to compute the flow-rate and torque losses due to internal leaks and friction. Use the Analytical if the block parameters are generally available from component data sheets. When you select Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses, the block uses lookup tables to map pressure gain, angular velocity, and displacement to component efficiencies or losses.

When you select Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses, the block performs the leakage flow rate and friction torque calculations the same as the Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses settings, respectively. When you select Input signal - volumetric and mechanical efficiencies, the block enables the **EV** and **EM** ports. You use these ports to specify the volumetric and mechanical efficiency. When you select Input signal - volumetric and mechanical losses, the block enables the **LV** and **LM** ports. You use these ports to specify the volumetric and mechanical losses.

### Nominal displacement — Displacement at which to specify volumetric efficiency

30 cm<sup>3</sup>/rev (default) | positive scalar

Fluid displacement for a given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the leakage flow rate and friction torque.

### Nominal shaft angular velocity — Shaft angular velocity for given volumetric efficiency

188 rpm (default) | scalar

Angular velocity of the rotary shaft that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the leakage flow rate and friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

### Nominal pressure gain — Pressure gain for corresponding volumetric efficiency

10 MPa (default) | scalar

Pressure gain that corresponds to the given volumetric efficiency. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

### Nominal dynamic viscosity — Dynamic viscosity at which to specify the volumetric efficiency

0.9 cP (default) | scalar

Dynamic viscosity of the hydraulic fluid for the given volumetric efficiency. These values are typically available at standard operating conditions in manufacturer data sheet. The block uses this parameter to calculate the internal leakage flow rate.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Volumetric efficiency at nominal conditions – Volumetric efficiency at specified nominal conditions

0.92 (default) | scalar in the range (0,1)

Volumetric efficiency for the given conditions. The block defines the volumetric efficiency as the ratio of actual to ideal volumetric flow rates. The standard operating conditions in the manufacturer data sheet typically list these values. The block uses this parameter to calculate the internal leakage flow rate.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Mechanical efficiency at nominal conditions – Ratio of ideal-to-actual mechanical power

0.88 (default) | positive scalar

Ratio of ideal mechanical power to actual mechanical power at nominal conditions.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### No-load torque – Minimum torque required to induce shaft rotation

0 N\*m (default) | scalar

Torque to overcome the seal friction and induce rotation of the mechanical shaft. This torque is the load-independent component of the total friction torque.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Analytical.

#### Pressure gain vector, dp – Pressure gains for given volumetric and mechanical efficiencies or losses

[.1, 1, 2] MPa (default) | vector

Pressure gains for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant, ( $\omega$ ,  $\Delta p$ ,  $D$ ). Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Shaft angular velocity vector,  $w$  – Angular velocities at which to specify volumetric and mechanical efficiencies or losses**

[25, 50, 100, 200, 300, 400] rad/s (default) | vector

Shaft angular velocities for the corresponding tabular efficiency or loss data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Displacement vector,  $D$  – Displacements at which to specify the volumetric and mechanical efficiencies or losses**

[-30, -19, 19, 30] cm<sup>3</sup>/rev (default) | vector

Displacements at which to specify the efficiencies or losses tabular data. The vector must be at least two elements in strictly increasing order.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies or Tabulated data - volumetric and mechanical losses.

**Volumetric efficiency table,  $e_v(dp,w,D)$  – Volumetric efficiencies for given pressure gains, angular velocities, and displacements**

repmat([.816, .908, .954, .977, .981, .984; .325, .663, .831, .916, .925, .946; .137, .568, .78, .892, .893, .91], 1, 1, 4) (default) | matrix

Volumetric efficiencies at the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must be in the range of 0-1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Mechanical efficiency table,  $e_m(dp,w,D)$  — Mechanical efficiencies for given pressure gains, angular velocities, and displacements**

```
repmat([.996, .996, .996, .996, .996, .996; .988, .989, .989, .989, .989, .99
; .981, .981, .982, .982, .983, .984], 1, 1, 4) (default) | matrix
```

Mechanical efficiencies that correspond to the specified fluid pressure gains, shaft angular velocities, and displacements. The efficiencies must be in the range of 0–1.  $M$ ,  $N$ , and  $L$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical efficiencies.

**Volumetric loss table,  $q_{loss}(dp,w,D)$  — Internal leakage flow rates for corresponding pressure gains, angular velocities, and displacements**

```
repmat([.0282, .0253, .0241, .0235, .0291, .0325; .2596, .1271, .1017, .0917,
.1216, .1142; .7874, .1901, .141, .1211, .1797, .1978] * 1e-3, 1, 1, 4) m^3/s
(default) | matrix
```

Volumetric losses at the specified fluid pressure gains, shaft angular velocities, and displacements. The block defines volumetric loss the internal leakage volumetric flow rate between port **A** and port **B**.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.
- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

**Mechanical loss table,  $torque_{loss}(dp,w,D)$  — Friction torques for corresponding pressure gains, angular velocities, and displacements**

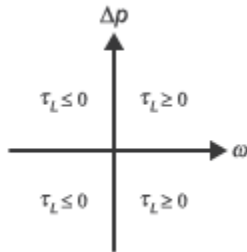
```
repmat([.002, .002, .002, .002, .002, .002; .06, .055, .055, .055, .055, .05;
.19, .19, .18, .18, .17, .16], 1, 1, 4) N*m (default) | matrix
```

Mechanical losses for the given pressure gains, shaft angular velocities, and displacements. The block defines mechanical loss as the friction torque due to seals and internal components.  $M$  and  $N$  are the sizes of the specified lookup-table vectors:

- $M$  is the number of vector elements in the **Pressure gain vector,  $dp$**  parameter.

- $N$  is the number of vector elements in the **Shaft angular velocity vector,  $w$**  parameter.
- $L$  is the number of vector elements in the **Displacement vector,  $D$**  parameter.

Specify the data for a single octant,  $(\omega, \Delta p, D)$ . Refer to “Operating Modes” on page 1-2069 for the operation modes corresponding to parameter specifications and the resulting octants. The tabulated data for the mechanical losses must obey the convention in the figure, with positive values at positive angular velocities and negative values at negative angular velocities.



#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Tabulated data - volumetric and mechanical losses.

#### Minimum volumetric efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs below this value.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Maximum volumetric efficiency – Upper saturation bound on volumetric efficiency input signal

1 (default) | scalar in the range (0,1)

Largest allowed value of the volumetric efficiency. The input from the physical signal port **EV** saturates inputs above this value.

#### Dependencies

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

#### Minimum mechanical efficiency – Lower saturation bound on volumetric efficiency input signal

1e-3 (default) | scalar in the range (0,1)

Smallest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs below this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Maximum mechanical efficiency — Upper saturation bound on volumetric efficiency input signal**

1 (default) | scalar in the range (0,1)

Largest allowed value of the mechanical efficiency. The input from the physical signal port **EM** saturates inputs above this value.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies.

**Pressure gain threshold for motor-pump transition — Pressure gain at which to initiate smooth transition between motor and pump modes**

1e-3 MPa (default) | scalar

Pressure gain from the inlet to the outlet below which the block begins to transition between the motor and pump modes. The block uses a hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Angular velocity threshold for motor-pump transition — Angular velocity at which to initiate smooth transition between pump and motor modes**

10 rad/s (default) | scalar

Shaft angular velocity below which the block begins to transition between the motor and pump modes. The block uses the hyperbolic tangent function to smooth the leakage flow rate and friction torque.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to Input signal - volumetric and mechanical efficiencies or Input signal - volumetric and mechanical losses.

**Cross-sectional area at ports A and B — Flow area at component inlet and outlet**

0.01 m<sup>2</sup> (default) | positive scalar

Flow area at the component inlet and outlet. The areas are assumed equal.

**Report when fluid is not fully liquid — Notification when fluid is not fully liquid**

None (default) | Warning | Error

Whether the block does nothing, generates a warning, or generates an error when the vapor quality is greater than 0, which indicates that the fluid is not fully liquid.

**Check if operating beyond the quadrants of supplied tabulated data – Simulation warning mode for operating conditions outside range of tabulated data**

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the range of tabulated data. If you select **Warning**, the block generates a warning when the fluid pressure gain or the shaft angular velocity cross outside the specified tabular data. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the range of tabulated data.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to:

- Tabulated data - volumetric and mechanical efficiencies
- Tabulated data - volumetric and mechanical losses

**Check if operating outside of pump mode – Simulation warning mode for operating conditions outside pump mode**

None (default) | Warning | Error

Simulation warning mode for operating conditions outside the pump mode. When you set this parameter to **Warning**, the block generates a warning if the pump transitions to motoring mode. The warning does not cause simulation to stop. If you select **Error**, the simulation will stop for conditions outside the pump mode.

**Dependencies**

To enable this parameter, set **Leakage and friction parameterization** to `Input signal - volumetric and mechanical losses`.

## Version History

**Introduced in R2022b**

## Extended Capabilities

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## See Also

Compressor (2P) | Positive-Displacement Compressor (2P) | Fixed-Displacement Pump (2P)



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