Pumps, Their Selection and Installation

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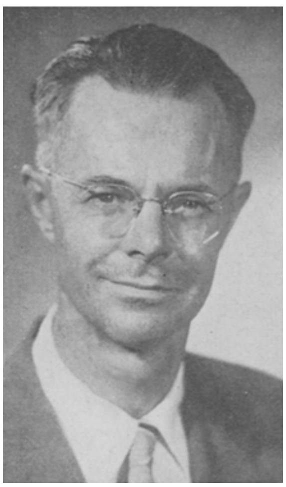
IN processing operations the most important method of transporting materials is by pumping them through pipes. At some time or other most engineers will have occasion to supervise the purchase, installation, operation, or maintenance of pumps. And a knowledge of the various types of pumps, their principles of operation, and operating characteristics is highly desirable. Materials which are handled by pumping range from fluidized solids through liquids to gases. These fluids may be highly corrosive or contain abrasive particles. They may be very fluid or highly viscous, and their temperatures may vary widely.



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The most commonly used pump today is the centrifugal, and there are many variations of this pump to meet the needs of industry. However the particular advantages of the many other types of pumps should not be overlooked in choosing one. A simplified classification of pump types is given as follows:

I. Reciprocating
- a) Piston
- b) Plunger
- c) Diaphragm

II. Rotary
- a) Gear
- b) Cam with valve
- c) Vane
- d) Screw

III. Centrifugal
- a) Volute
- b) Diffusion
- c) Turbine
- d) Mixed Flow

IV. Coaxial
- a) Deep well propeller
- b) Low Lift

Each type of pump has its own particular advantages, which make it particularly suited for a certain type of job. However there is much overlapping in the uses of the various pumps, and the optimum choice is determined by a study of the economics involved. The major cost factors include the initial cost, maintenance costs, and power costs. A rough recommendation of the economic ranges of operation is shown in Figure 1.

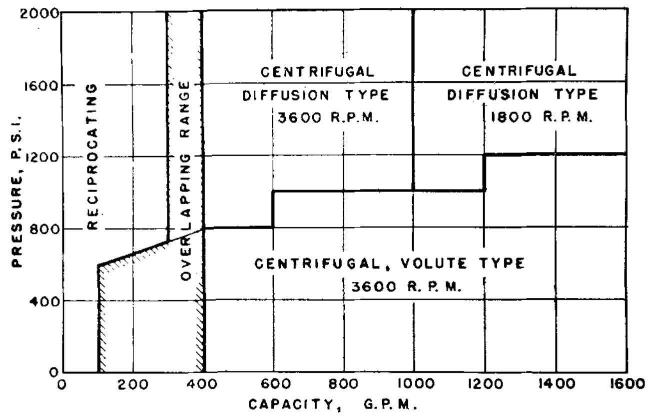

FIG. 1. Suggested economic operating ranges for reciprocal and centrifugal boiler feed pumps. (Kristal and Annett, "Pumps," McGraw-Hill Book Company Inc., New York, 1940.)

Reciprocating Pumps

Reciprocating pumps are one of the oldest types, and a great many are still in service. New pumps of this type are frequently warranted. They deliver a constant volume of fluid against a wide range of pressures and can be built to operate at very high pressures. They are self-priming and have high volumetric efficiencies.

However the valves prevent satisfactory operation on viscous materials, and the sliding action and close tolerances cause maintenance problems, especially when the fluid contains suspended abrasive particles.

The two most commonly used types of piston pumps are the direct acting, steam-driven simplex and duplex pumps. The first has a single steam cylinder and a single fluid cylinder while the second has two steam and two fluid cylinders acting together. These pumps are usually double-acting, except for those intended for high pressures. The duplex pump is a rugged, simple machine. It is dependable in operation, and has a smoother flow than the simplex.

The ratings for capacity and discharge head for a reciprocating pump are based on the piston diameters, length of stroke, and maximum recommended piston speed. A pump designated as a 10 x 8 x 12 size would have a 10-in. dia. steam piston, 8-in. dia. fluid piston, and a 12-in. stroke. The increase in fluid pressure is obtained by:

$$\triangle \text{ P fluid} = \triangle \text{ P Steam} \left(\frac{\text{steam cyl. dia.}}{\text{fluid cyl. dia.}} \right)^2 \text{ x Mech Eff.}$$

Another reciprocating pump which has long been used in the cottonseed industry is the power-driven plunger pump which has been used in hydraulic systems. The difference between the plunger and piston pump is that the packing for the plunger is on the cylinder while the piston pump has sealing rings similar to an automobile piston. The plunger pump is used for higher pressures and has more resistance to abrasive wear than the piston pump. Power-driven, variable stroke plunger and piston pumps are quite often used for feeding operations.

Diaphragm Pumps

The diaphragm pump is very useful for handling slurries since it has no sliding surfaces in contact with the fluid pumped. In general, this pump is used where relatively low pressures are required because of the limitations of a mechanically operated diaphragm. However high pressures may be obtained by some pumps in which the diaphragm is actuated by a secondary fluid which is pulsated by a piston or plunger.

Rotary Pumps

The rotary class of pumps includes vane, screw, gear, cycloidal, and others. They are particularly adapted to viscous fluids which cannot be handled satisfactorily by reciprocating or centrifugal pumps. Their positive action and smooth discharge make them desirable for metering and feed purposes. They will operate with high suction heads, and they are suitable for direct connection to electric motors. However an overload relief valve should be used. Self priming, high heads, high capacities, and small size are other added advantages. Because of close tolerances and wiping action, they should not be used with fluids having poor lubricating properties or suspended abrasive particles.

Centrifugal Pumps

Basically the centrifugal pump consists of an impeller, having two or more radial vanes of various shapes and curvatures, which rotates in a circular housing. Fluid enters at the axis or eye of the impeller and is discharged with high momentum around the periphery into a collecting space where momentum is converted to pressure head. The design of the impeller greatly affects pump performance. In general, high capacity moderate head pumps have vanes with considerable backward curvature while high head pumps have vanes of little curvature. Curvature has little or no effect on the pressure at closed discharge. Efficiency is increased by using closed impellers having seals or wear rings of close contact with the case to prevent high pressure fluid from leaking back to the intake. A volute type pump has a collecting space of increasing cross section better to convert the velocity head to pressure head, and in some pumps a diffusion ring of stationary vanes is used to give a venturi effect in expanding the cross-section of flow.

There are several standard types of centrifugal pumps used in industry. The single-stage, single-suction volute type is a low-cost pump for general service and may be obtained with capacities up to 1,500 gal./min. and for heads up to 600 ft. For larger capacities and moderate pressures, the single-stage, double-suction type is more often employed, and the multi-stage volute type may be obtained with sufficient stages for almost any desired head.

Since the centrifugal pump is by far the most used type at present, the factors affecting its selection will be emphasized. The performance of this type of pumps may be conveniently expressed, as shown in Figure 2, by curves of brake horsepower, efficiency, and total head as a function of throughout in gal./min.

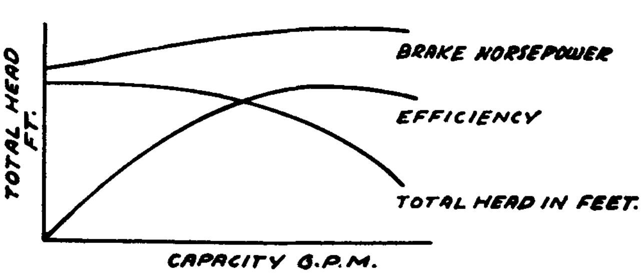

FIG. 2. Typical operating curves for a centrifugal pump.

Frequently it is desirable to alter the performance of a given pump to fit a particular job. This may be done in three ways.

The effect of changing the design of the impeller vanes is shown in Figure 3. The general characteristic curve has a fairly wide range of capacity with little change of head. The rising performance curve would have a large increase in power consumed as the pump is opened up.

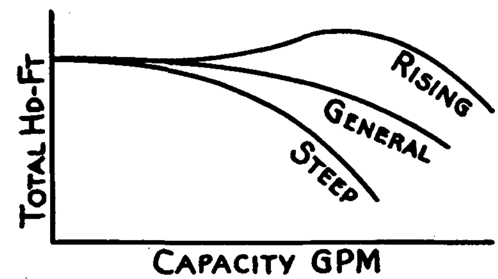

FIG. 3. Head-capacity curves showing effect of impeller pitch.

A second method of changing pump performance is to change the diameter of the impeller. In this method the effect on the characteristic curves will be as follows:

a) The discharge or capacity varies directly as the diameter.
b) The head varies as the square of the diameter.
c) The efficiency will remain the same for small changes.
d) The power varies as the cube of the impeller diameter.

The effect of changing impeller diameter on the operating curves of a given pump is shown in Figure 4.

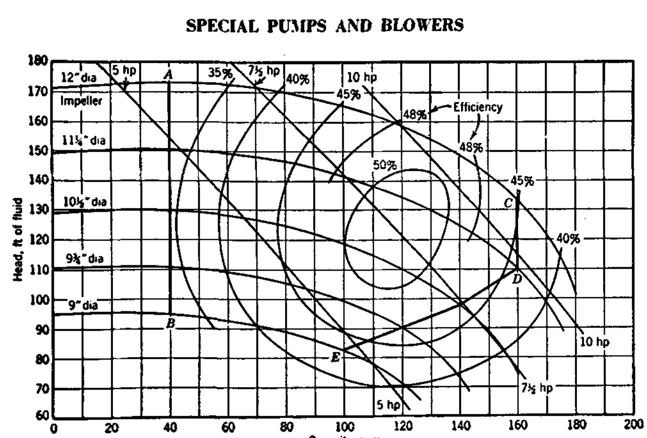

FIG. 4. The effect of impeller diameter on the characteristics of a centrifugal pump with enclosed impellers operating at 1,750 rpm. Lines of equal efficiencies and brake horsepowers are shown. (Aurora Pump Co.)

Of course, there are limitations in the range of impeller diameters that may be used. Too large an impeller will cause turbulence in the casing, and the impeller cannot be cut so small that the blades will not overlap, or the operation will be unstable.

A third method is to change the speed of rotation. The effect on operation is as follows:

a) The capacity varies directly as the speed.
b) The head varies as the square of the speed.
c) The efficiency will remain the same for small changes.
d) The power varies as the cube of the speed.

The effect of impeller speed on the operating curves is shown in Figure 5. Use of this method is limited to the availability of motor speeds and by decreasing efficiency with speed.

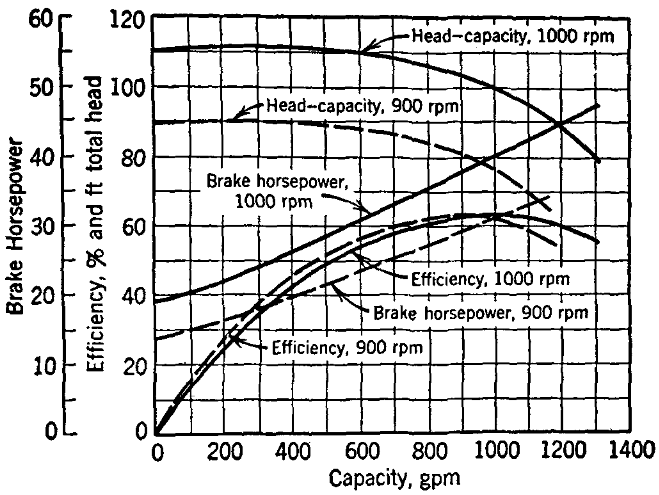

FIG. 5. Head, efficiency, and brake horsepower, versus capacity for a centrifugal pump operating at two speeds with the same liquid. (Worthington Pump and Machinery Corp.)

For a single-stage pump or one stage of a multistage pump, the specific speed is a convenient concept:

$$N_s = \frac{RPM \sqrt{gpm}}{H\ 3/4}$$

N_s = Specific speed.
H = Developed head.

This form of the ratio has been simplified from a more basic form which is a dimensionless ratio if consistant units are used. By plotting the efficiencies of the single-stage pump against the specific speed, one may determine the proper speed for maximum efficiency of operation or if the speed is fixed, the most efficient number of stages may be obtained.

In preparing the specifications to be supplied to the manufacturer for the purchase of a pump, a number of factors should be considered.

Properties of Fluid. Although it is best to specify the exact fluid to be handled, this is not always feasible, and a general term such as vegetable oil or caustic solution may be used. The physical properties of vapor pressure, specific gravity, and viscosity are given for the temperature of operation. If any suspended solids are to be present, the nature of these and the percentage by volume should be noted. If solids are abrasive, a slower speed pump will reduce wear. The corrosive property of the fluid is an important factor, and consideration should be given to the pump materials which will withstand attack and whether or not the corroded metal would be an objectionable contaminant, such as copper in oil. There is the possibility of galvanic action if dissimilar metals are in contact, and high liquid velocities in pumps may greatly accelerate corrosive activity.

Quantity to be Handled. It is necessary to select a pump which will handle the maximum capacity, yet it should not be so oversized that excessive throttling is necessary. It is desirable that the pump will operate in its range of highest efficiency while handling the normal load.

Suction Conditions. The maximum range of suction pressure is important since it directly affects the discharge pressure. The extremes of suction pressure should be considered in its effect upon the maximum and minimum allowable discharge pressures. The suction pressure is obtained by subtracting the friction pressure drops from the pressure at the level of the fluid supply point.

The net positive suction head (N.P.S.H.) is the difference between the absolute suction pressure and the vapor pressure of the fluid at suction temperature. This is of great importance in the operation of pumps with suction pressures below atmospheric and with fluids having high vapor pressures.

Piping Considerations. Piping will be considered here only as it affects pump operation.

Pressure drops, due to friction, are obtained from standard flow tables and by the use of the Fanning friction factor which is a function of Reynolds' Number and a pipe roughness factor. Friction in the suction lines should be kept at a minimum if the N.P.S.H. value is low; whereas friction in the discharge system is usually determined by the economic size of piping.

The suction lines should be as short as possible and slope upward to the pump to avoid air traps. All piping should be firmly supported, and care should be taken that pipe expansion stresses are not transmitted to the pump. The pump discharge line usually has a control valve and a check valve with a by-pass line for priming.

Sample Pump Selection Problem

In a hypothetical case soybean oil is to be pumped at a constant rate of 100 gal./min. from a storage tank through a preheater and into a reaction vessel which is to be maintained at 50 p.s.i.g. pressure. The process is continuous, and a diagram is shown in Figure 6. Design data are given as follows:

Suction line diameter = 4 in.
Discharge line diameter = 3 in.
Pressure drop in suction line for 100 gal./min. = .16 lb./sq. in.
Pressure drop in discharge line exclusive of control valve, orifice, and exchanger for 100 gal./min. = 5.9 lb./sq. in.
Pressure drop through orifice = 3 lb./sq. in.

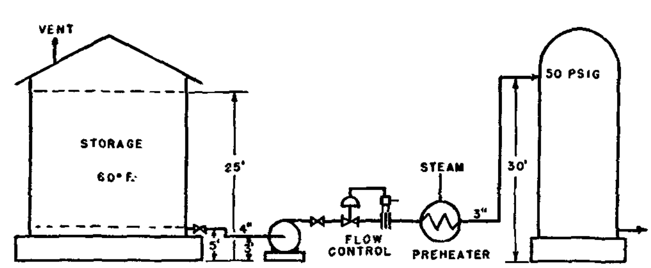

FIG. 6. Flow diagram for pump selection problem.

Pressure drop through exchanger at 100 gal./min. = 12 lb./sq. in.

Pressure at reactor = 50 lb./sq. in. gauge.

Minimum temperature in storage tank = 60°F.

Temperature after preheating = 210°F.

Specific gravity at 60°F. = 0.924

Specific gravity at 210°F. = 0.870

Design Calculations:

Maximum flow assumed to be 25% greater than normal = 125 gal./min.

Minimum flow assumed to be 25% less than normal = 75 gal./min.

At maximum flow the pressure drops due to friction or as follows:

Suction line $(0.16)(1.25)^2 = 0.25$ psi
Discharge line $(5.9)(1.25)^2 = 9.2$ psi
Exchanger $(12)(1.25)^2 = 18.8$ psi

Pump Suction Pressure

Maximum will be when tank is full.

$$\text{Pressure} = 14.7 + (25\text{-}3)\frac{(0.924)(62.4)}{(144)} - 0.25 = 23.2 \text{ psia.}$$

Minimum will be when tank level is at bottom outlet.

$$\text{Pressure} = 14.7 + (5\text{-}3)\frac{(0.924)(62.4)}{144} - 0.25 = 15.3 \text{ psia.}$$

Since the vapor pressure of the oil is negligible, the net positive suction pressure will be 15.3 psia.

Discharge Pressure at Maximum Flow

The discharge pressure is obtained by totaling the pressure drops due to friction, the static head, and the pressure head at the point of discharge. The pressure drop through the flow control valve at maximum flow will arbitrarily be taken as 10% of the total friction drops.

Control valve pressure drop

$$= \frac{(9.2 + 18.8 + 3)\ (.10)}{.90} = 3.4 \text{ psi}$$

Static head at discharge point

$$= \frac{(30\text{-}3)\ (.870)\ (62.4)}{144} = 10.2 \text{ psi}$$

Total Discharge Pressure

$$= 9.2 + 18.8 + 3 + 3.4 + 10.2 + 50 + 14.7 = 109.3 \text{ psia.}$$

Pressure increase required of pump

$$109.3 - 15.3 = 94.0 \text{ psi}$$

If the maximum allowable downstream pressure is set at 150 p.s.i.g., the maximum allowable $\triangle$ P across the pump will be:

$$(150 + 14.7) - 23.2 = 141.1 \text{ psi}$$

Since the method of flow control would require smooth pressure and non-positive action, two centrifugal pumps (one spare) are recommended.

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