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ELECTRO-ANALOG MODELS FOR HEAT EXCHANGERS AND A SIMPLIFIED METHOD FOR HEAT EXCHANGER CALCULATIONS

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Abstract—Electrical direct analog models of the basic types of heat exchangers are described. Data obtained from parallel- and counter-flow heat exchanger models are presented in form of dimensionless temperature distribution curves. These curves simplify the heat exchanger calculations. Auxiliary curves obtained from the same data eliminate iteration from basic heat exchanger calculations.

NOMENCLATURE

A, area;
a, ratio of heat capacities;
C, electrical capacitance;
$\dot{C}$, heat capacity;
h, film coefficient;
i, electrical current;
k, coefficient of thermal conductivity;
q, rate of heat transfer;
R, electrical resistance;
$\dot{R}$, electrical resistance corresponding to $\dot{C}$;
t, electrical time;
Δ, temperature difference;
δ, thickness;
θ, ratio of temperature differences;
τ, time constant.

Subscripts

c, cold;
e, electrical;
h, hot;
i, inlet;
m, mean;
o, outlet.

INTRODUCTION

HEAT exchanger calculations are normally carried out by using methods involving logarithmic mean temperature difference (LMTD) and correction factor charts or the "number of transfer units" concept and effectiveness tables. The calculations require iteration in some cases and may become quite cumbersome if the most economic type and size of heat exchanger for some given data is to be determined.

Using dimensionless temperature distribution curves (DTDC) for heat exchangers simplifies these calculations to a great extent and by using auxiliary curves or tables, iterations may completely be eliminated. The calculations of LMTD or effectiveness becomes unnecessary and the solution of a problem is reduced to dimensioning the dimensionless parameters according to a given data.

DTDC for different types of heat exchangers may be obtained from mathematical models by using digital computers or by using electrical direct-analog computers. DTDC presented here are restricted to parallel- and counter-flow heat exchangers and are obtained from mathematical and electrical direct-analog models which are very simple. Data for other types of heat exchangers are under preparation and will be published soon. The fundamental concepts governing the construction of electrical models are reviewed and the basic circuits for different types of heat exchangers are described in the following sections.

FUNDAMENTAL CONCEPTS

Following the usual method in establishing analog relations, first the governing laws for the system (heat exchanger) will be stated in the form of equations. Being the simplest type, parallel flow heat exchangers will be used for the statement of the conservation of energy law.

$$q = -\dot{C}_h \Delta T_h = UA\Delta T_m = \dot{C}_c \Delta T_c. \qquad (1)$$

In this chain of equations $\dot{C}$ represents the product of the mass rate of flow and the specific heat of fluids. The meaning of the other symbols are indicated in Fig. 1.

Ohm's law is suggested by equations (1), since they also state that the energy transferred is proportional to the potential gradient. The constant of proportional-

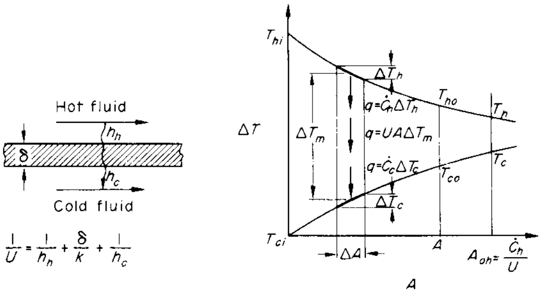

FIG. 1. Nomenclature used in heat equations.

ity for both equations represent the transmissibility of the transfer media.

$$i = -\frac{\Delta u_h}{\dot{R}_h} = \frac{\Delta u_m}{R} = \frac{\Delta u_c}{\dot{R}_c}. \tag{2}$$

Accordingly, heat potential difference will be analogous to electrical potential difference and heat flow to electrical current (Fig. 2).

Thermal equations | Electrical equations

$$\frac{dq}{dA} = U\Delta T_m \qquad i = \frac{1}{R}.\Delta u_m$$
$$\frac{dq}{dA} = -\dot{C}_h\frac{dT_h}{dA} = \dot{C}_c\frac{dT_c}{dA} \qquad i = -C_{eh}\frac{du_h}{dt} = C_{ec}\frac{du_c}{dt}. \tag{3}$$

As observed from equations (3) and Fig. 3, for this type of analogy, heat-transfer area will be represented by electrical time. If U is expressed in terms of unit length of the heat exchanger, electrical time will represent the length of the thermal system.

The time constant τ for the (RCN) models furnishes a convenient link between electrical and thermal data through the following relations:

Using the definition $\tau = RC_e$ and the analog relations indicated on Fig. 3

$$\tau = \frac{\dot{C}}{U} = A_o$$

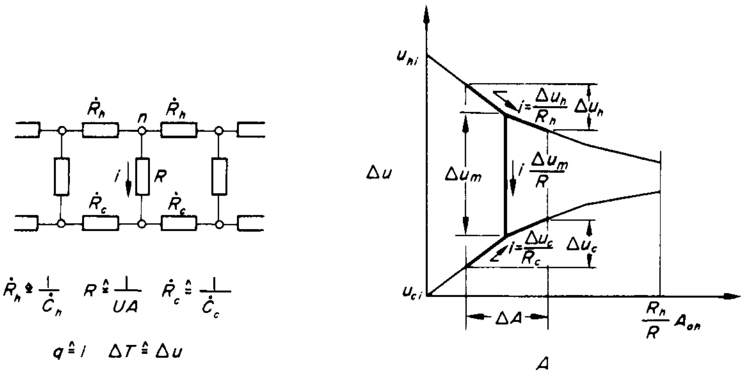

FIG. 2. Nomenclature used for lumped resistance network models (LRN) and the corresponding analog relations.

The overall coefficient of heat transfer U, as defined here is an average value including the fouling factor and variation of the film coefficients along the system. As such, it expresses the amount of heat transferred per unit surface area of the system for a temperature difference equal to the logarithmic mean of the inlet and outlet temperature differences under the prevailing conditions. U may also be defined per unit length of the system for heat exchangers having a constant cross-section.

The lumped resistance network (LRN) shown in Fig. 2 gives only approximate similarity since a continuous field is represented by discrete elements.

An exact similarity may be obtained for heat exchangers by using resistance–capacitance network (RCN) models. To establish the electro-analog relations, the heat equations will be stated in differential form and slightly modified.

is obtained. Due to the existing analogy, A_o may be called the "area constant" and is indicative for the relative energy transfer rate with respect to heat transfer surface area.

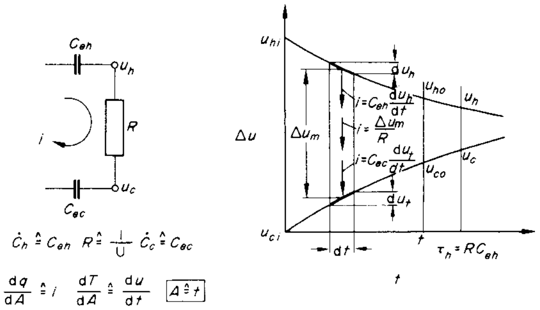

FIG. 3. Nomenclature used for resistance capacitance network models (RCN) and the corresponding analog relations.

Thermal relations	Electro-analog relations	
$A_{oh} = \dfrac{\dot{C}_h}{U}$	$\tau_h = RC_{eh}$	(4)
$A_{oc} = \dfrac{\dot{C}_c}{U}$	$\tau_c = RC_{ec}$.	

Further, for a parallel flow heat exchanger

$$A_o = \frac{\dot{C}_h \dot{C}_c}{U(\dot{C}_h - \dot{C}_c)}.$$

The overall area constant A_o is an important criteria in economical optimization calculations for heat exchangers. Since the area ratio for any two sections of a heat exchanger must be equal to the corresponding time ratio of the RCN the following relations exist.

$$A = \frac{A_o}{\tau} t. \tag{5}$$

Using relations (4) and (5), voltage–time curves obtained from RCN models may directly be used to evaluate thermal data.

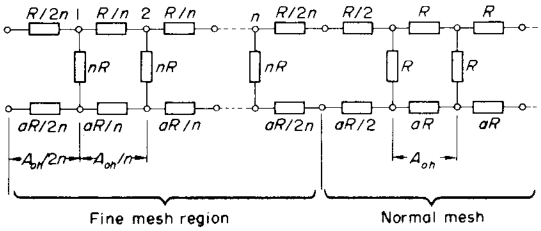

FIG. 4. Lumped resistance network (LRN) for hot side standard.

Similar relations may be obtained for the LRN analogy, providing a link between the axial resistances $\dot{R}$, cross-resistances R and area A represented by each unit. Taking arbitrarily $R = \dot{R}_h$ (hot side standard) and setting $\dot{C}_h/\dot{C}_c = a$ results in the following relations (Fig. 4):

$$A_{oh} = \frac{\dot{C}_h}{U} \qquad \dot{R}_h = R$$

$$\dot{R}_c = aR \qquad \Delta T_h = \Delta T_m. \tag{6}$$

Electrical circuits for the models of some of the most common types of heat exchangers have been built, tested and are described in the following sections. Data collection work on cross-flow heat exchangers with one side mixed and both sides unmixed is being carried on. Models for other types of heat exchangers or heat exchanger units in combination may be built by combining electrical models. But this is usually not necessary, since in practically all cases the solution of problems may be achieved by linking data obtained from the DTDC for the basic heat exchanger types.

Combination of (LRN) models is always possible, whereas the combination possibility of the (RCN) models is limited. One example for such an (RCN) combination, introduced here, will be the U-tube and shell exchanger model. The cross-flow type of exchangers with both fluids unmixed can not be simulated by an (RCN) model and (LRN) models must be used, giving point data for curve plotting. An electrolytic tank model would give the possibility of continuous curve tracing. Cross-flow heat exchangers with one side fully mixed can be simulated by a hybrid model consisting of a combination of (LRN) and (RCN) parts.

The model for evaporators and condensers is very simple and consists of a simple R–C unit, generating a single curve. DTDC for condenser–evaporators appear as the ($a = 0$) line both on the parallel- and counter-flow heat exchanger curves (Figs. 13 and 18).

PARALLEL-FLOW HEAT EXCHANGER MODEL

The model consists of two electrical capacitors, and one resistance. To supply the model with current, a constant voltage power supply and to trace the curves two high input impedance voltage followers and one CRO equipped with a camera were used (Fig. 5). The time constant of the models were around 1 s. An $X-Y$ or $X-Y-Y$ plotter may also be used for curve tracing. In that case, however, the time constant of the models should be increased to about 10 s at least, to minimize the inertial effects of the tracer.

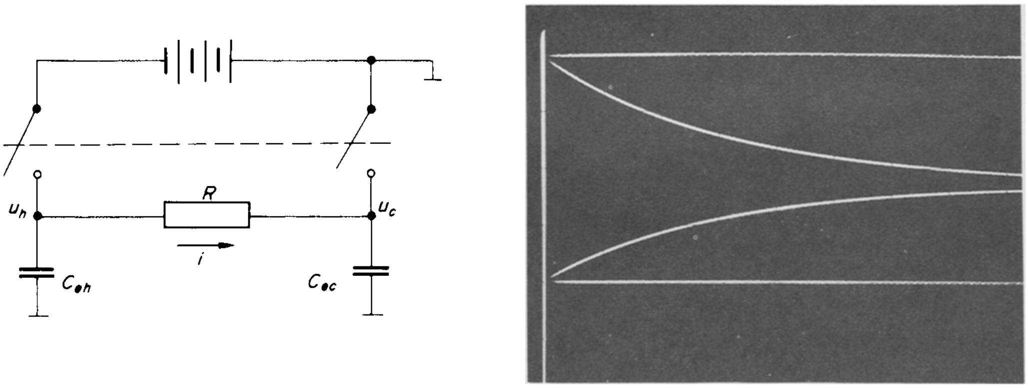

FIG. 5. Parallel-flow heat exchanger model and photographically obtained sample data.

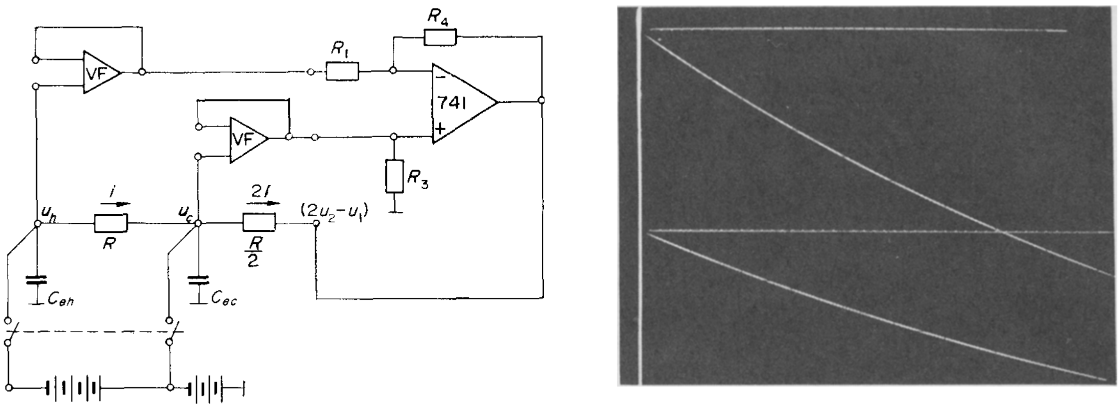

FIG. 6. Counter-flow heat exchanger model and photographically obtained sample data.

COUNTER-FLOW HEAT EXCHANGER MODEL

For this type of heat exchanger model an automatic control circuit had to be developed for continuous and accurate curve tracing [1]. The circuit shown in Fig. 6 has proven to be very reliable and accurate. The time constant for the models were again selected around one second.

U-TUBE AND SHELL MODEL

This model is a combination of the parallel-flow and counter-flow (RCN) models. The electric circuit for the case, where both fluids enter from the same side is shown in Fig. 7.

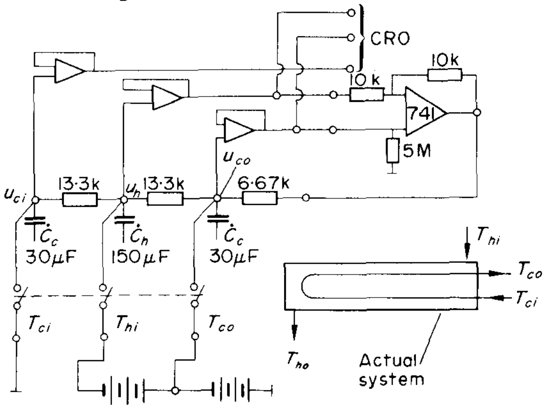

FIG. 7. U-tube and shell model, both fluids enter from the same side.

Figure 8 gives one sample data obtained from a U-tube and Shell model. This data is valid up to the point where the parallel- and counter-flow curves cut each other, this point indicating the U-bend section of the pipes.

CROSS-FLOW HEAT EXCHANGERS

Cross-flow heat exchangers with one side fully mixed may be simulated by a hybrid model as shown in Fig. 9, which essentially consist of an LRN parallel-flow heat exchanger model and RCN evaporator or condenser model. Average fluid outlet temperatures may be obtained by methods previously described [2]. Temperature distribution curves for this type of heat exchanger may also be calculated by using the DTDC for parallel-flow heat exchangers.

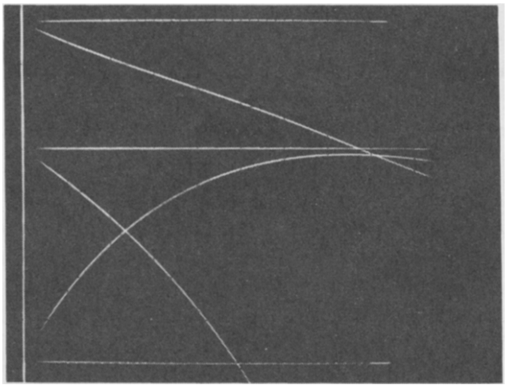

FIG. 8. Photographic sample data obtained from the RCN model shown in Fig. 7.

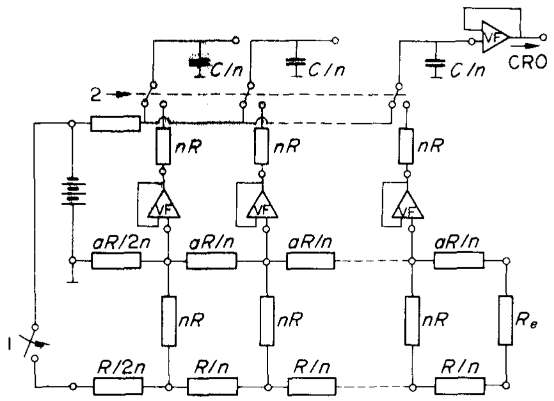

FIG. 9. Hybrid model for cross-flow heat exchangers with one side fully mixed, the other unmixed.

For the case where both fluids are unmixed or the case where one fluid is only partially mixed, LRN models must be used. Figure 10 shows part of the fluid inlet corner of a crossflow heat exchanger where both fluids are unmixed.

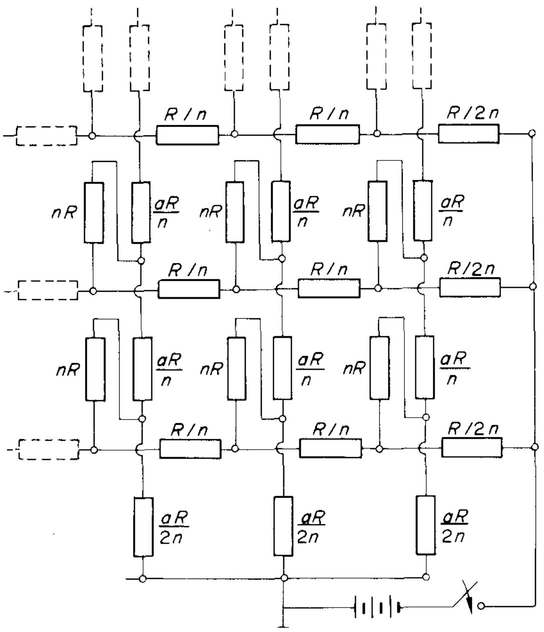

FIG. 10. Part of LRN model of a cross-flow heat exchanger with both sides unmixed (active elements not shown).

DIMENSIONLESS TEMPERATURE DISTRIBUTION CURVES

Voltage–time curves, photographically obtained from RCN models are the DTDC for the system with the heat capacity ratio $\dot{C}_h/\dot{C}_c = a$ as a parameter, which in turn is equal to the ratio of the electrical capacitances of the model. Taking parallel-flow as basis for the following explanations, the heat exchanger inlet temperature difference (initial voltage applied to the model) is standardized to one (i.e. 100 per cent). The horizontal time axis on the photograph is marked by vertical lines at $\tau_h = RC_{eh}[s]$ intervals, each interval representing one unit of the dimensionless ratio $NTU = UA_{oh}/\dot{C}_h$ for the system (Fig. 11). The dimensionless ratio NTU (number of transfer units) [3] has been used here without the restriction $\dot{C}_{min}$, in other words, it may also be true that $NTU = UA/\dot{C}_{max}$.

Considering the simple case were the inlet and outlet temperatures, the overall coefficient of heat transfer U, and the heat capacity ratio a, is known, the surface area corresponding to the given data may be determined by using the following relations:

$$\theta_h = \frac{T_{hi} - T_{hc}}{T_{hi} - T_{ci}} \quad \text{or} \quad \theta_c = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}. \tag{7}$$

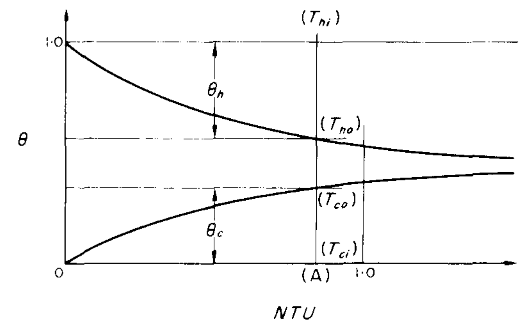

FIG. 11. DTDC for parallel-flow heat exchanger, $a = 0{\cdot}8$, reproduced from sample data of Fig. 5.

Locating either one of these values on the ordinate of the DTDC and drawing a horizontal line to cut the temperature curve will determine the value of NTU as the abscissa of this point of intersection (Fig. 11). The surface area may then be calculated according to equation (8).

$$A = (NTU)\frac{\dot{C}_h}{U}. \tag{8}$$

A will have the dimensions that were used for the definition of U.

Up till now specifications such as "hot side" and "cold side" were used with the aim of simplifying the explanations. At this point the equations will be expressed in a more general form for later use.

Equations (1), (7) and (8) may be written as:

$$q = C_{max} \quad \Delta T_{min} = UA \quad \Delta T_m = C_{min} \quad \Delta T_{max} \tag{9}$$

$$\theta_{min} = \frac{\Delta T_{min}}{\Delta T_{in}} \qquad \theta_{max} = \frac{\Delta T_{max}}{\Delta T_{in}} \tag{10}$$

$$A = (NTU)\frac{C_{min}}{U} \quad \text{or} \quad A = (NTU)\frac{C_{max}}{U} \tag{11}$$

where $\Delta T_{in} = T_{hi} - T_{ci}$ for parallel-flow and for counter-flow it is either $\Delta T_{in} = T_{hi} - T_{co}$ or $\Delta T_{in} = T_{ho} - T_{ci}$ depending on whichever the greater value has.

The following generalized charts for DTDC are based on these equations.

To prepare a generalized chart for parallel- and counter-flow heat exchangers the DTDC for different values of a must be superimposed on a single θ vs NTU plane. But this would cause the curves to cut each other in such a way that reading the chart would become practically impossible. Therefore, the generalized presentation of the DTDC for the parallel flow heat exchangers was carried out in the following way: The θ_{max} side temperature distribution curves were rotated by 180° around the horizontal $\theta = 0{\cdot}5$ axis as shown in Fig. 12.

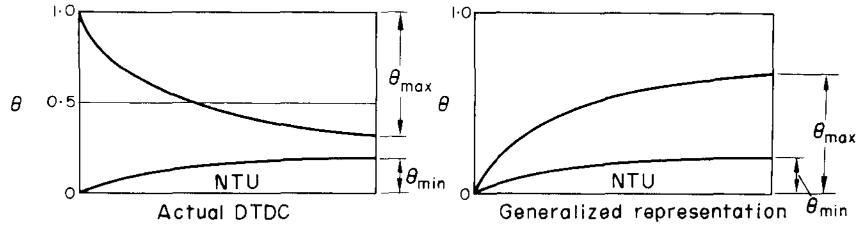

FIG. 12. Rotation of the θ_{max} curve to permit easy reading of the generalized chart (Fig. 13).

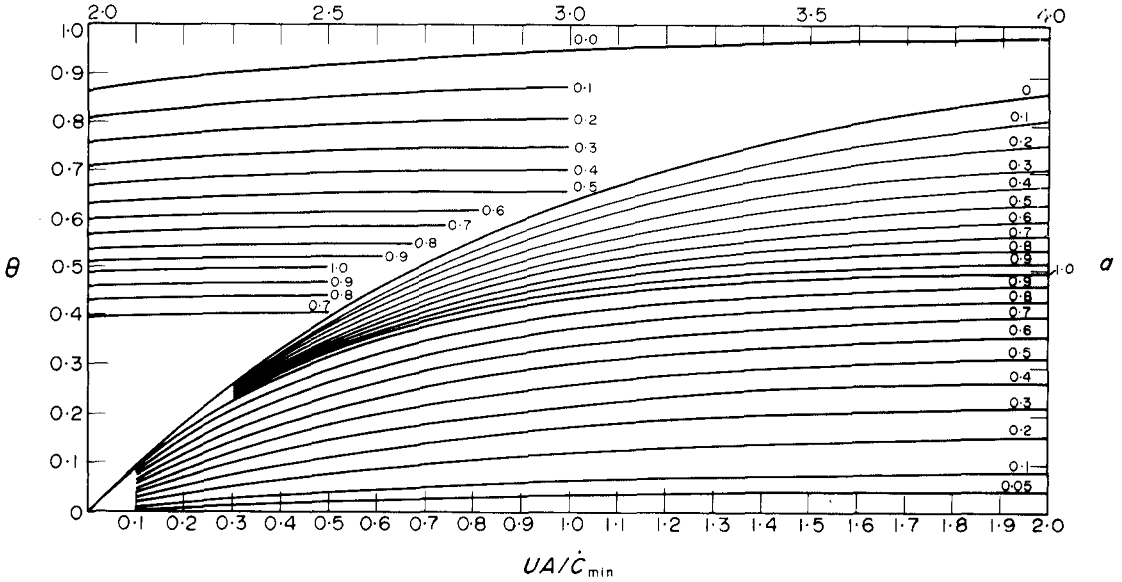

FIG. 13. DTDC for parallel-flow heat exchangers, $NTU = UA/C_{min}$.

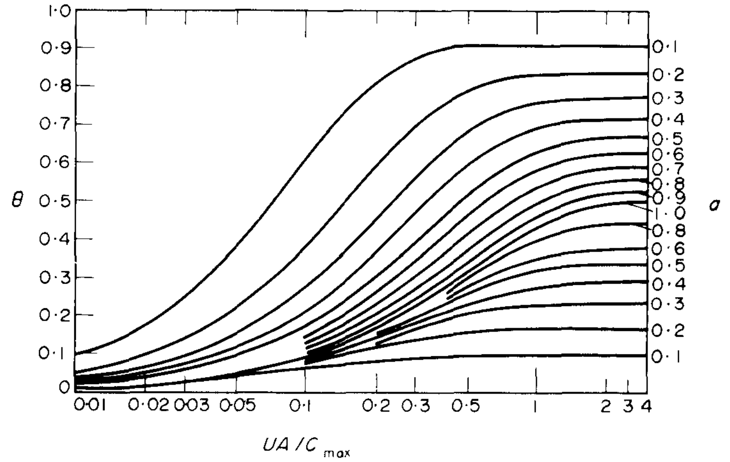

FIG. 14. DTDC for parallel-flow heat exchangers, $NTU = UA/C_{max}$.

Figure 13 is prepared on this basis, giving the parallel-flow DTDC for heat capacity ratios $a = 0$ to $a = 1{\cdot}0$. Due to symmetry, a second chart for $a > 1{\cdot}0$ is not necessary. For the cases, where (a) is not known beforehand and $\dot{C}$ given is found to be the greater one (i.e. $\dot{C}_{max}$), Fig. 14 must be used to determine the value

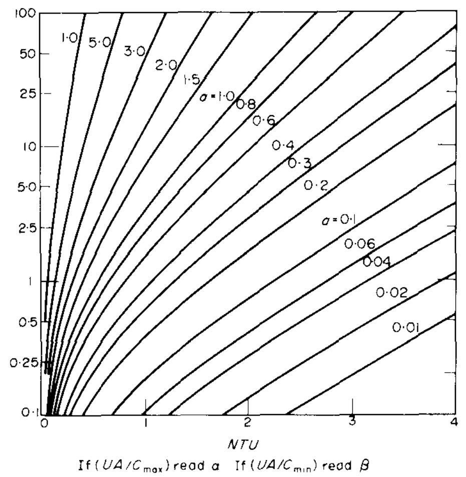

FIG. 15. α and β values for parallel-flow heat exchangers.

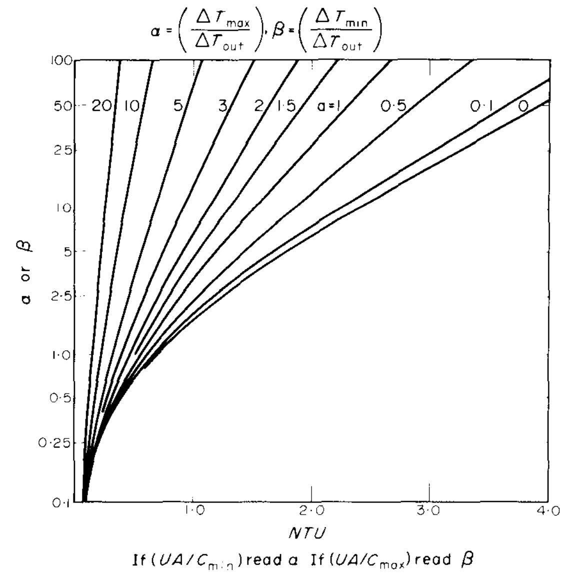

FIG. 16. α and β values for parallel-flow heat exchangers.

of (a) without iteration. Figures 15 and 16 are needed in case (a) cannot be determined from the given data and only one inlet temperature and both outlet temperatures are given. The method of using Figs. 13–16 will be explained in the following section.

APPLICATION OF DTDC

The parameters encountered in simplified heat exchanger calculations can be grouped as follows:

Group	A	B	C	D
Parameter	$T_{hi}\,T_{ho}\,T_{ci}\,T_{co}$	UA	$\dot{C}_h\,\dot{C}_c$	9

Since there are nine parameters and three equations (equations 1) relating them, six of the parameters must be given, including at least one parameter from group B.

The following examples are classified from a point of view of DTDC application into three groups. Dimensions will not be given, since any consistant system of units may be used.

(1) In this group of problems the heat capacity ratio a can directly be calculated from the given data by using one of equations (12).

$$a = \frac{\dot{C}_{min}}{\dot{C}_{max}} \quad \text{or} \quad a = \frac{\Delta T_{min}}{\Delta T_{max}}. \tag{12}$$

Problems are solved simply by using the DTDC-chart for parallel-flow, Fig. 13.

Example 1

Given: $T_{hi} = 200 \quad T_{ho} = 160 \quad U = 10^3$
$T_{ci} = 20 \quad T_{co} = 120 \quad \dot{C}_c = 10^4.$

Calculate: Surface area A required.
Solution: In accordance with equations (9)–(12).

$$\Delta T_h = \Delta T_{min} \quad \dot{C}_h = \dot{C}_{max} \quad \Delta T_c = \Delta T_{max} \quad \dot{C}_c = \dot{C}_{min}$$

$$A = NTU \cdot \frac{\dot{C}_{min}}{U}\left(\text{since Fig. 13 has } NTU = \frac{UA}{\dot{C}_{min}}\right)$$

$$a = \frac{\Delta T_{min}}{\Delta T_{max}} = \frac{200-160}{120-20} = 0{\cdot}4$$

$$\theta_{max} = \frac{120-20}{200-20} = 0{\cdot}555.$$

Entering Fig. 13 for these two values gives $NTU = 1{\cdot}07$

$$A = \frac{\dot{C}_{min}}{U}.NTU = \frac{10^4}{10^3} \times 1{\cdot}07 = 10{\cdot}7 \qquad \boxed{A = 10{\cdot}7}$$

(2) In this group of problems the heat capacity ratio (a) cannot be determined from the given data. Inlet temperatures are given.

Example 2

Given: $T_{hi} = 200$ $T_{ho} = 130$ $T_{ci} = 60$
$U = 10^3$ $A = 120$ $\dot{C}_c = 10^5$.

Calculate: Heat capacity required for the hot side and cold fluid outlet temperature.

Solution: Assume $\dot{C}_c = \dot{C}_{min}$, accordingly $\theta_h = \theta_{min}$

$$\theta_h = \frac{200-130}{200-60} = 0{\cdot}5 \qquad \frac{UA}{\dot{C}_c} = \frac{10^3 \times 120}{10^5} = 1{\cdot}2.$$

Entering Fig. 13 with these two values it is found that θ_h falls in the region above the curve for $a = 1$ which indicates that $\theta_h = \theta_{max}$, therefore $\dot{C}_c = \dot{C}_{max}$.

This result shows that Fig. 14 which has the correct NTU scale namely UA/C_{max}, must be used.

From Fig. 14, $a = 0{\cdot}85$. Using equations (12), $\dot{C}_h$ and ΔT_c can be calculated

$\boxed{\dot{C}_h = 0{\cdot}85 \times 10^5}$ $\Delta T_c = 60$ $\boxed{T_{co} = 120}$ $q = 6 \times 10^6$.

Figure 16 is valid for the assumption that $UA/\dot{C}_{min}$ and α are known, giving the value $a = 1{\cdot}8$. Entering Fig. 15 for the values $NTU = 0{\cdot}8$ and $a = 1{\cdot}8$ gives $\beta = 5{\cdot}4$.

Both a and β values indicate that the assumption made was wrong. If $\dot{C}_h$ would be $\dot{C}_{min}$, a would be less than one and β must always be less than α or at least equal to it ($a = 1$). A second trial is not necessary since the values found already give the correct answer in the following form:

$$\dot{C}_h = \dot{C}_{max} \quad \dot{C}_{max}/\dot{C}_{min} = 1{\cdot}8 \quad \alpha = 5{\cdot}4 \quad \beta = 3$$

$$\Delta T_c = \Delta T_{max} = 5{\cdot}4\,(80-70) = 54 \quad \boxed{\dot{C}_c = 695} \quad \boxed{T_{ci} = 16.}$$

For the generalized counter-flow heat exchanger DTDC-presentation, similar to parallel flow, a rotation of the θ_{min} curve by 180° around an axis perpendicular to the θ–NTU plane at the zero point was carried out as shown in Fig. 17. The curve was further shifted

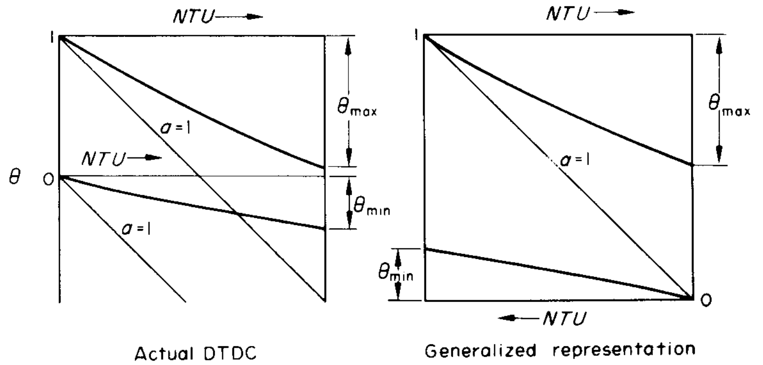

FIG. 17. Rotation of θ_{min} curve to permit easy reading of the generalized chart (Fig. 18).

(3) In this last group only one inlet temperature and both outlet temperatures are given. Heat capacity ratio is unknown.

To simplify the explanation of solving these kind of problems the following definitions will be introduced:

$$\Delta T_{out} = T_{ho} - T_{co} \qquad \alpha = \frac{\Delta T_{max}}{\Delta T_{out}} \qquad \beta = \frac{\Delta T_{min}}{\Delta T_{out}}. \quad (13)$$

Example 3

Given: $T_{hi} = 110$ $T_{ho} = 80$ $T_{co} = 70$
$U = 500$ $A = 2$ $\dot{C}_h = 1250$.

Calculate: $\dot{C}_c$, T_{ci}.

Solution: Assume $\dot{C}_h = \dot{C}_{min}$ then $\Delta T_h = \Delta T_{max}$

$$\alpha = \frac{110-80}{80-70} = 3$$

$$\frac{UA}{\dot{C}_{min}} = \frac{500 \times 2}{1250} = 0{\cdot}8.$$

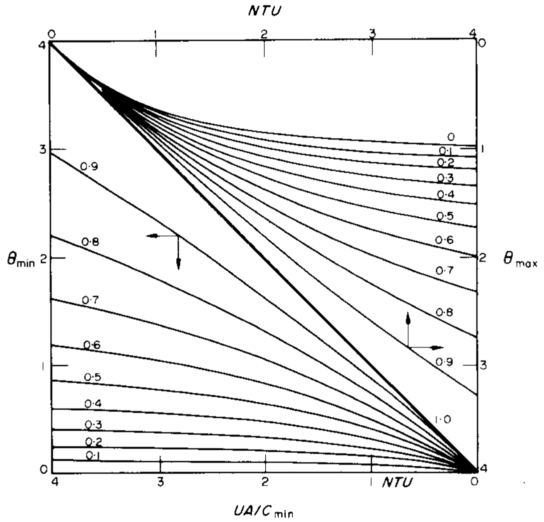

FIG. 18. DTDC for counter-flow heat exchangers, $NTU = UA/\dot{C}_{min}$.

in the NTU axis direction in such a way that the $a = 1$ lines will overlap.

Figure 18 is prepared on this basis. This chart may be used for all cases where a is known. For the cases where a is not known beforehand, curves corresponding to Figs. 14–16 are needed. These curves and others will be published later, as mentioned before, with more complete data on heat exchangers.

The use of Fig. 18 will be clarified with the following numerical examples.

Example 4

For a counter-flow heat exchanger the following data is given

$$T_{hi} = 200 \quad T_{ho} = 80 \quad U = 150$$
$$T_{co} = 100 \quad T_{ci} = 40 \quad \dot{C}_h = 3 \times 10^4.$$

Calculate the surface area required.

Solution: From the given data, the following values are calculated by using equations (9)–(12)

$$a = \frac{100-40}{200-80} = 0{\cdot}5$$

$$\theta_{min} = \frac{100-40}{200-100} = 0{\cdot}6 \qquad \theta_{max} = \frac{200-80}{200-100} = 1{\cdot}2$$

Entering Fig. 18 with these values it is found that $NTU = 1{\cdot}84$

$$A = 1{\cdot}84 \times \frac{3 \times 10^4}{150} \qquad \boxed{A = 368}$$

Example 5

Data given: $T_{hi} = 200 \quad T_{ho} = 120 \quad \dot{C}_h = 3{\cdot}5 \times 10^4$
$T_{co} = 160 \quad U = 150 \quad \dot{C}_c = 2 \times 10^4$
it follows that $T_{ci} = 20$.

Calculate: The surface area required.

Although this problem is the same as example 4 with respect to the given parameters, in this case $\dot{C}_c = \dot{C}_{min}$ and therefore the temperature difference at the cold fluid entrance side of the heat exchanger is greater than the temperature difference at the hot fluid entrance side. This fact should be considered for the θ_{min} and θ_{max} calculations in equations (10) in such a way that for ΔT_{in} this greater value must be used. This change in definition is based on a symmetry for counter-flow heat exchanger DTDC, which is somewhat similar to the parallel-flow DTDC symmetry, only in this case the axis of symmetry is perpendicular to the θ–NTU plane.

Solution:

$$\theta_{min} = \frac{200-120}{120-20} = 0{\cdot}8 \qquad \theta_{max} = \frac{160-20}{120-20} = 1{\cdot}4$$

$$a = \frac{200-120}{160-20} = 0{\cdot}571.$$

Entering Fig. 18 with these values we obtain $NTU = 2{\cdot}14$

$$A = 2{\cdot}14 \times \frac{2 \times 10^4}{150} \qquad \boxed{A = 285.}$$

Example 6

Data given: $T_{ho} = 75 \quad U = 10^3 \quad \dot{C}_h = 4 \times 10^4$
$T_{ci} = 15 \quad A = 40 \quad \dot{C}_c = 2 \times 10^4.$

Calculate: T_{hi}, T_{co} and q.

Solution: From the given data

$$a = 0{\cdot}5 \qquad \frac{UA}{C_{min}} = 2.$$

Entering Fig. 18 with these values gives $\theta_{min} = 0{\cdot}635$, $\theta_{max} = 1{\cdot}27$

$$\frac{\Delta T_h}{75-15} = 0{\cdot}635 \quad \Delta T_h = 38$$
$$\frac{\Delta T_c}{75-15} = 1{\cdot}27 \quad \Delta T_c = 76$$

$$\boxed{T_{hi} = 113 \quad T_{co} = 91 \quad q = 1{\cdot}52 \times 10^6.}$$

As it can be observed from the given examples, in comparison to the classical methods, the usage of DTDC simplifies the heat exchanger calculations to a great extent and iterations may completely be eliminated.

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MODELES ELECTRO-ANALOGIQUES ET METHODE SIMPLE DE CALCUL DES ECHANGEURS DE CHALEUR

Résumé—On décrit les modèles analogiques électriques de types d'échangeurs de chaleur classiques. On présente, sous forme de courbes de distribution de la température adimensionnelle, les résultats obtenus sur les modèles des échangeurs à courants parallèles et à contre-courant. Ces courbes simplifient les calculs des échangeurs de chaleur. Des courbes auxiliaires obtenues dans les mêmes cas éliminent les calculs classiques par itération.

ELEKTRO-ANALOGIE-MODELLE FÜR WÄRMEÜBERTRAGER UND EINE VEREINFACHTE METHODE ZUR BERECHNUNG VON WÄRMEÜBERTRAGERN

Zusammenfassung—Elektro-Analogie-Modelle für Grundtypen von Wärmeübertragern werden beschrieben. Die von Modellen von Gleich- und Gegenstromwärmeübertragern erhaltenen Werte werden in Form von dimensionslosen Temperatur verteilungskurven dargestellt. Diese Kurven vereinfachen die Berechnung von Wärmeübertragern. Zusätzliche Kurven ersetzen die von den Grundtypen von Wärmeübertragern ausgehende iterative Berechnung.

ЭЛЕКТРОАНАЛОГОВЫЕ МОДЕЛИ ТЕПЛООБМЕННИКОВ И УПРОЩЕННЫЙ МЕТОД ИХ РАСЧЕТА

Аннотация — Описываются электроаналоговые модели основных типов теплообменников. Данные по параллельным и противоточным моделям теплообменников представлены в виде кривых распределения безразмерной температуры, которые упрощают расчеты теплообменников. Полученные на основе этих данных вспомогательные кривые позволяют избегать итерации при расчете основных теплообменников.