

Use Computers to Select Exchangers

The discussion here will help you decide whether a digital computer is worth its cost. A sample program is proposed to show the steps to take in rating a typical exchanger

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DOES YOUR COMPANY still rate (size) heat exchangers by hand? Most hand rating is unnecessary if you have at least a medium size digital computer.

In this article are aids in deciding whether a computer has economic justification. After reading this you should be able to decide the minimum computer size for your purpose. If you have a computer, you will find a sample program set-up here and heat transfer information reduced to a form the computer can use.

Here is what you can do on a digital computer. First you supply it with the necessary process and mechanical specifications. The computer can then supply:

- Number of exchangers and arrangement
- Surface
- Shell diameter and length
- Number of tube passes
- Pressure drop of both streams
- Over all heat transfer coefficient
- Baffle pitch and cut

It is also possible to calculate body flange dimensions, over-all dimensions, weight and manufacturing costs.

WHAT SIZE COMPUTER?

Dimensional size or price of a computer is not necessarily a true indication of its capacity. With the nature of our problem in mind, the best means of computer classification is by the amount of memory it has.

Computer memory is measured in quantities called words. A word can be either a number or a command for the computer to perform. In the case of number storage the number of digits per word varies between computers. Usually there are 7-10 digits per word.

In selecting a computer, be careful when comparing memory capacity. Some computers do not have all of their memory available for computation. This unavailable memory is used for functions common to any program. Other computers get around this by using circuitry instead of memory to accomplish the same thing.

As previously mentioned a memory word usually consists of 7-10 digits. Since usage of more than three significant figures in heat transfer computations is questionable, part of the word is not being utilized. It is possible in some computers to make a more effective use of the memory. This is done by ingeniously storing more than one piece of information in a memory location. This is particularly effective in storing tables.

The minimum computer size for our purpose is approximately 1,000 words of storage. This will do only simple exchangers (liquid to liquid). Another limitation is that it is necessary to hand calculate the physical properties of the fluids and the corrected log mean temperature difference. These variables are included in the input to the computer rather than being calculated by the computer.

Those computers with approximately 4,000 words of

	SHELL	TUBE
Inlet Temperature, °F.	_____	_____
Outlet Temperature, °F.	_____	_____
Flow Liquid (excluding water), lb./hr.	_____	_____
Water, lb./hr.	_____	_____
Gas, lb./hr.	_____	_____
Condensing steam, lb./hr.	_____	_____
Specific Heat, Btu/lb.	_____	_____
Viscosity (avg.), cp.	_____	_____
Viscosity (wall), cp.	_____	_____
Oil Specific Gravity @ 60° F.	_____	_____
Liquid Density (avg.), lb./cu. ft.	_____	_____
Gas Molecular Weight	_____	_____
Compressibility Factor	_____	_____
Operating Pressure, psia	_____	_____
Allowable Pressure Drop, psi	_____	_____
Film Coefficient (if known)	_____	_____
Heat Load, Btu/hr.	_____	_____
Max. Over-all Transfer Coefficient	_____	_____
Tube O.D., in.	_____	_____
Tube BWG	_____	_____
Tube Length, ft.	_____	_____
Tube Pitch (1) 15/16, (2) 1, (3) 1-1/8, or (4) 1-1/4	_____	_____
Overall fouling	_____	_____
Shell Design Pressure, psi	_____	_____
Corrosion Allowance, in.	_____	_____

FIGURE 1—For computers having a capacity of less than two thousand words, this input form will be changed slightly.

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storage will catch, with a few exceptions, all the usual heat transfer applications. This includes services such as multi-component condensing, vaporizing and two phase flow. Also this includes several different types of exchangers such as floating head, U-tube and fixed tube sheet.

HOW MUCH FASTER IS THE COMPUTER?

First the question must be answered how fast is it done by hand? An experienced rating engineer will average about five selections per day or approximately one every ninety-five minutes. If an engineer rates only occasionally, then he will probably average 1-4 per day depending on his experience. In an extreme case a rating will take as much as two days. A breakdown of the time required by a typical computer rating is seen in Table 1.

Step	Minutes
Input sheet (Fig. 1).....	3
Transfer to computer.....	2
Computation	1 to 5
Specification sheet	1
Total.....	7 to 11

Since there are many possible combinations of input-output equipment and computers, Table 1 is intended only as a guide. In evaluating the speed of a particular installation watch out for input-output time. This factor doesn't always receive the full consideration it deserves. In our case it requires more than half the total time.

With a little arithmetic we see a computer is approximately 8-11 times faster than the experienced rater. If a large computer is used then ratings can be made faster.

BLOCK DIAGRAMING

A major portion of solving a problem by computer is in block diagraming. A block diagram is an outline or flowchart of the problem. From this diagram and the necessary equations, a step by step procedure can be written that the computer can follow (this is a program). This procedure is written in the language of the computer at hand.

The two main problems in programming are:

- Converting engineering data to a form that can be used by the computer.
- Including all possible situations the computer will encounter.

SAMPLE PROGRAM

A program which will rate condensers, vaporizers and exchangers with two phase flow in several different types of equipment is quite complex. The program presented here will be a relatively simple one which can be modified to include these refinements. Also it is limited to a floating head type exchanger with two or more tube passes and a single pass shell.

The nature of the programming will depend on the computer size. With small computers it may be necessary to be repetitive to conserve memory space. For example, on a small computer each time the machine tries a new shell size it starts with two tube passes and increases in passes until pressure drop is met. On a pro-

gram for a large computer it would not be necessary to start with two tube passes. By using extra instructions it could start with the number of tube passes used on the previous shell size.

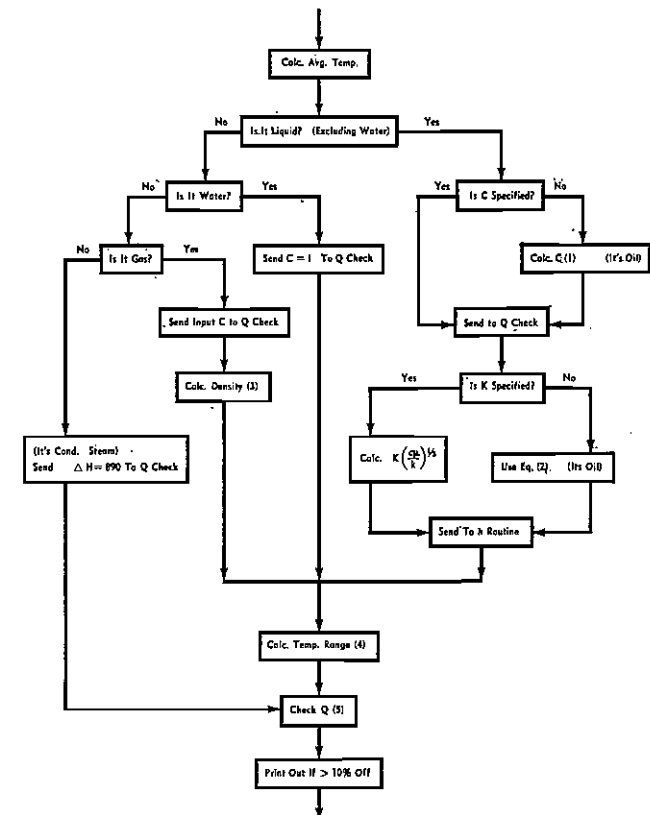
INPUT

The input format can be seen in Figure 1. For computers smaller than two thousand words this form will be slightly changed. For these smaller computers the physical properties, heat load check and corrected log mean temperature difference are calculated by hand and included in the input.

FLUID IDENTIFICATION AND PROPERTIES

The first computer step after the input is loaded is to identify the fluids on the shell and tube sides. A block diagram of the fluid identification and properties subroutine is given in Figure 2. After identification the properties are assembled and transferred to where they will be used in the program. In order to save valuable memory space this same routine is used for both the shell and tube sides.

A fluid is identified by a search of the input storage. For example if there is a zero in the flow input for



$$c = 0.681 - 0.308 \text{ S.G.} + t_a (0.000815 - 0.000306 \text{ S.G.}) \quad (1)$$

$$K (c\mu/K)^{1/2} = 0.15 \mu^{1/2} \quad (2)$$

$$\text{Gas } \rho = \frac{\text{M.W. } P_o}{10.7 Z (460 + t_a)} \quad (3)$$

$$\begin{aligned} (\text{Shell}) \Delta t_s &= t_{s1} - t_{s2} \\ (\text{Tube}) \Delta t_e &= t_{e2} - t_{e1} \end{aligned} \quad (4)$$

$$\begin{aligned} Q &= WC\Delta t \text{ or} \\ Q &= WA\Delta H \end{aligned} \quad (5)$$

FIGURE 2—This program will check the input heat load.

water then the computer knows that it is some other substance. Thus it in effect answers the question, "Is it water?"

There are three sources from which this routine can assemble properties. They are as follows:

- Input data
- By calculation
- Within the sub-routine

Those properties requiring excessive memory capacity to calculate are included in the input. An example of this is liquid viscosity. Properties which are constant over a wide temperature range are stored within the sub-routine. An example of this is the specific heat of water.

If the process stream is identified as oil, the specific heat is calculated² from Equation (1) in Figure 2. This equation is based on a characterization factor of 11.8. If the oil has a significantly different factor a multiplier must be used with Equation (1). The multiplier can be obtained from the expression $0.055K + 0.35$ where K is the characterization factor.

It is not necessary to supply a thermal conductivity value to the input for the previously mentioned oil. By

means of Equation (2) the function $K(c\mu/k)^{1/4}$ for heat transfer can be calculated. It is necessary to supply only the viscosity. This relationship is based on thermal conductivity data from Figures T-11 and T-11 A in the 1954 addenda to TEMA.² The coefficient of 0.15 used in the equation is an average value. The lighter hydrocarbons through hexane reflect a coefficient of 0.148. From Hexane through 50° API oil the coefficient is 0.152. The coefficient decreases with gravity to a low of 0.145 for 37° API and heavier oils. This use of an average coefficient is justified when the large variation of thermal conductivities in the literature is considered.

After the properties are assembled they are transferred to where they will be used. For instance the specific heat is sent to the heat load check and also the heat transfer coefficient routine.

This program is based on the premise the heat load is supplied by an external source. The machine will rough check the input heat load rather than supply it. If it is desired for the machine to calculate and supply its own heat load then only a slight modification in the program is necessary. After the heat load is calculated

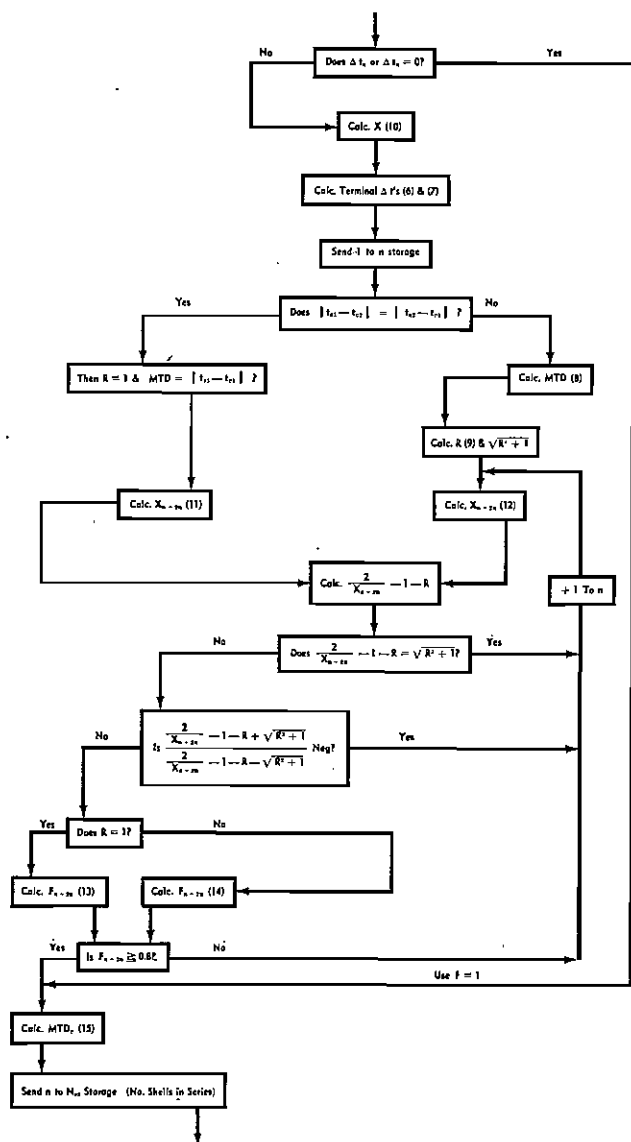


FIGURE 3—The program for corrected mean temperature difference should not be used if you are limited in memory space.

$$|T_{s1} - T_{c2}| \quad (6)$$

$$|T_{s2} - T_{c1}| \quad (7)$$

$$MTD = \frac{GTD - LTD}{\ln(GTD/LTD)} \quad (8)$$

$$R = \Delta t_s / \Delta t_c \quad (9)$$

$$X = \frac{\Delta t_c}{|T_{s1} - T_{c1}|} \quad (10)$$

$$\text{When } R = 1 \quad (11)$$

$$X_{n-2n} = \frac{X}{n - nX + X}$$

$$X_{n-2n} = \frac{1 - \left(\frac{1 - RX}{1 - X}\right)^{1/n}}{R - \left(\frac{1 - RX}{1 - X}\right)^{1/n}} \quad (12)$$

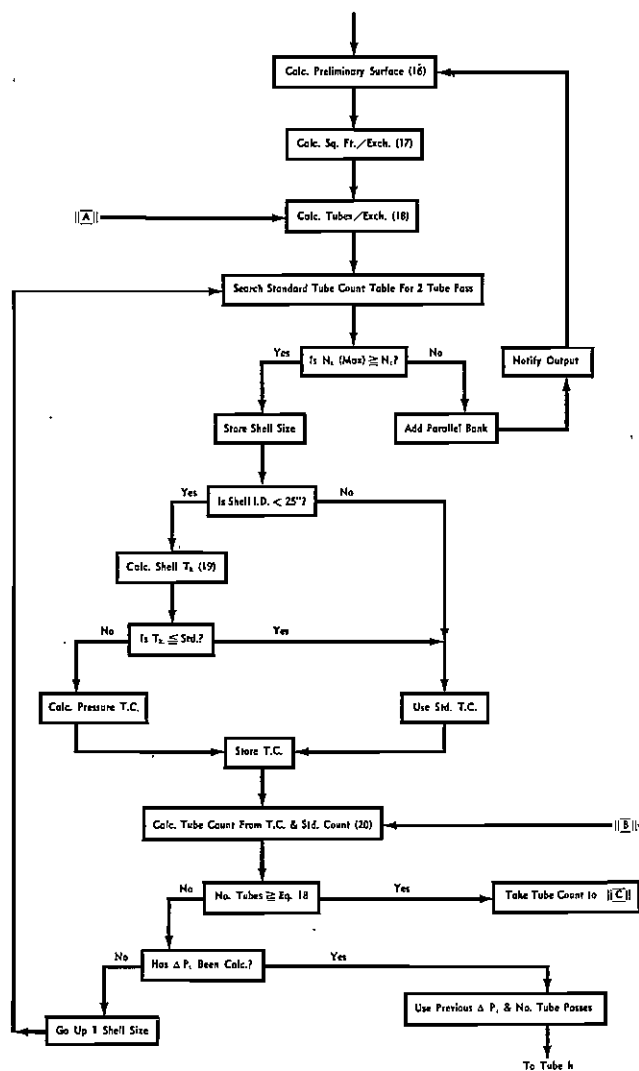
$$\text{When } R = 1 \quad F_{n-2n} =$$

$$1.414 \left(\frac{X_{n-2n}}{1 - X_{n-2n}} \right) \ln \left(\frac{\frac{2}{X_{n-2n}} - 1 - R + \sqrt{R^2 + 1}}{\frac{2}{X_{n-2n}} - 1 - R - \sqrt{R^2 + 1}} \right) \quad (13)$$

$$F_{n-2n} =$$

$$\frac{\sqrt{R^2 + 1}}{R - 1} \ln \left(\frac{1 - X_{n-2n}}{1 - RX_{n-2n}} \right) \ln \left(\frac{\frac{2}{X_{n-2n}} - 1 - R + \sqrt{R^2 + 1}}{\frac{2}{X_{n-2n}} - 1 - R - \sqrt{R^2 + 1}} \right) \quad (14)$$

$$MTD_c = MTD(F) \quad (15)$$



$$A_t = \frac{Q}{MTD_o U_{max}} \quad (16)$$

$$Sq. Ft./Exch = A_t / N_{es} N_{ep} \quad (17)$$

$$N_T = A / (Sq. In./Ft.) (L) \quad (18)$$

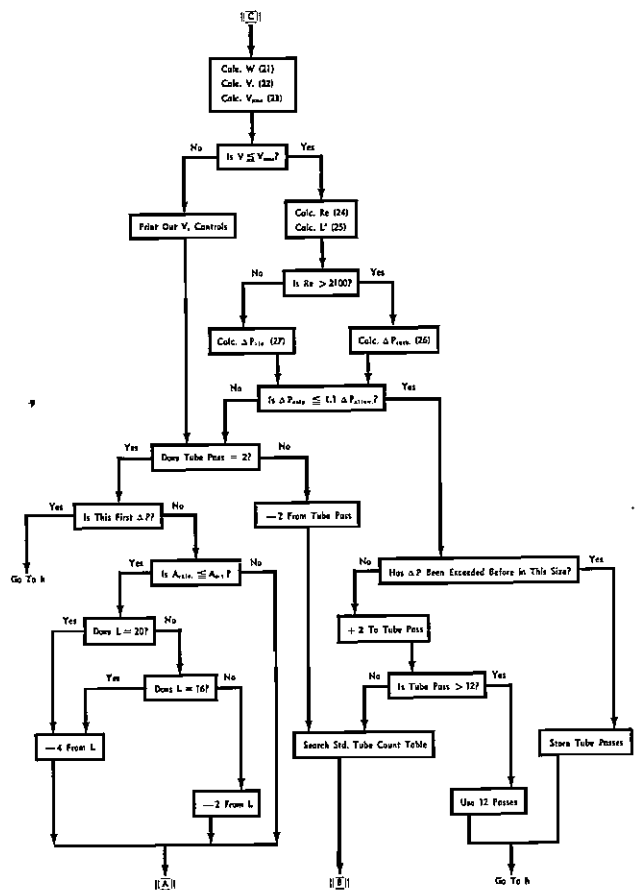
$$T_k = \frac{(P) (r_s)}{15,000 - 0.6 P} + \text{Corrosion Allowance} \quad (19)$$

$$\text{Count} = \left(\frac{\text{Pressure Tube Circle}}{\text{Standard Tube Circle}} \right)^2 \quad (20)$$

FIGURE 4—The function of this routine is to keep track of the exchanger arrangement and the shell size. Points A, B, and C refer to Figure 5 also.

by means of Equation (5) it is checked against the input head load. If the difference is more than 10 percent then the calculated head load is printed out. Then the flow or temperature range can be changed in the input accordingly. With a large computer this change in input could be programmed to be done automatically.

When the heat load for condensing steam is checked an average latent heat of 890 Btu/lb is used. This value will check within 10 percent of the heat load for steam pressures ranging from atmospheric to 300 psi.



$$W = W_t N_p / N_t N_{ep} \quad (21)$$

$$V_t = .051 W / d_i^2 \rho \quad (22)$$

$$V_{max} = \frac{\sqrt{(\text{To Be Inserted})}}{\sqrt{\rho}} \quad (23)$$

$$Re = 6.31 W / d_i \mu \quad (24)$$

$$L' = (L + 5.55 d_i) N_p N_{es} \quad (25)$$

$$\Delta P_{turb.} = \frac{6.38 W^{1.8} L' \mu^{0.2}}{10^7 d_i^{4.8} \rho (\mu / \mu_w)^{0.14}} \quad (26)$$

$$\Delta P_{vis.} = \frac{4.08 W \mu L'}{10^5 d_i^4 \rho (1.1 \mu / \mu_w)^{0.25}} \quad (27)$$

FIGURE 5—A relatively large amount of logic is required for calculating the tube side pressure drop.

CORRECTED MEAN TEMPERATURE DIFFERENCE

The simplest way of obtaining a mean temperature difference (MTD) correction by hand is by using the curves in TEMA.² The machine procedure as can be seen in Figure 3 is not as easy. Unless one can spare the memory space it is debatable whether putting it on the machine is advisable.

Fortunately we do not need six different equations for one to six shell pass correction factors. We can use one equation if we modify the X variable for each case. Usually we can calculate X_s for a desired number of shells in series, by Equation (12).⁵ Then this X is inserted in Equation (14)^{3,4} to obtain F.

As can be seen in Figure 3 the first time the correction factor F is equal to or greater than 0.8 then an exit

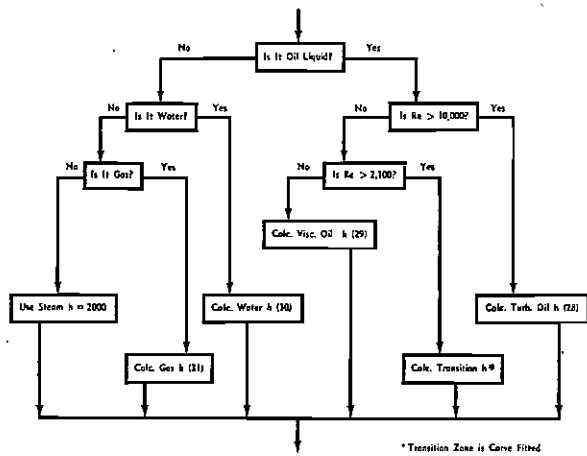
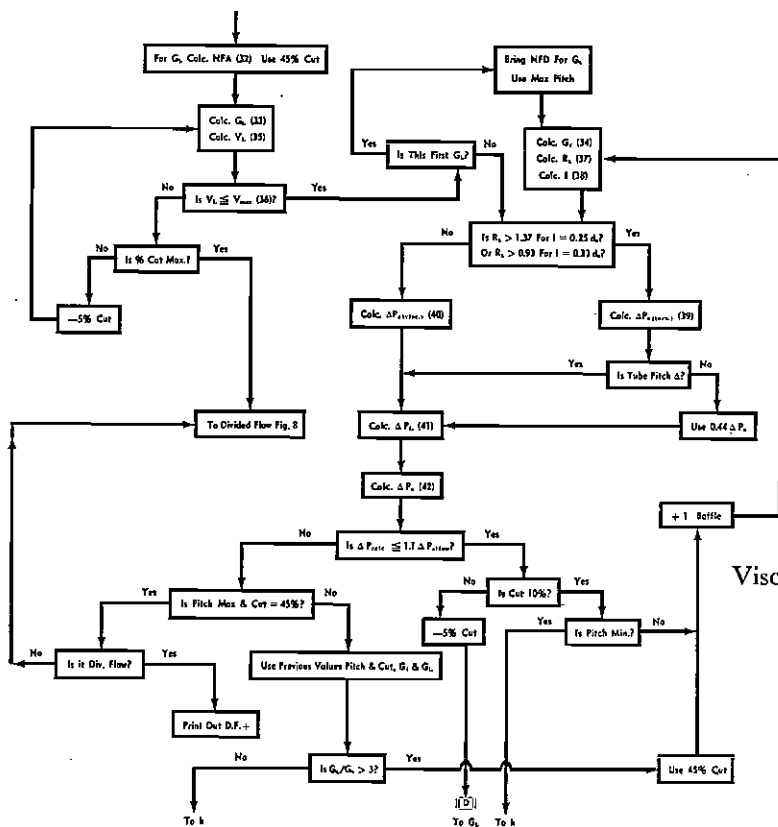


FIGURE 6—The tube side film coefficient depends upon the type of flow within the tubes.



$$NFA = \pi R_B^2 - 0.785 N_t d_o^2 \quad (32)$$

$$G_L = 0.04 W_s / (NFA) (\% \text{ Cut}) \quad (33)$$

$$G_x = 0.04 W_s / (NFD) (P) \quad (34)$$

$$V_L = G_L / \rho_B \quad (35)$$

$$V_{max} = 40 / \sqrt{\rho_B} \quad (36)$$

$$R_x = d_o G_x / \mu_B \quad (37)$$

$$l = \text{Tube Pitch} - d_o \quad (38)$$

$$\text{Turbulent } \Delta P_x = 0.000124 \frac{\mu^{0.2} G_x^{1.8}}{l^{0.2} \rho_B} N (B + 1) \quad (39)$$

$$\text{Viscous } \Delta P_x = 0.0000522 \frac{\mu G_x}{l \rho_B} N (B + 1) \quad (40)$$

$$\Delta P_L = G_L^2 B / 5950 \rho_B \quad (41)$$

$$\Delta P_B = \Delta P_x + \Delta P_L \quad (42)$$

FIGURE 7—This program for shell side pressure drop is designed to discover special cases promptly. Point D refers to a supplemental program shown in Figure 8.

is made and the corrected MTD calculated. From the X_{n-2n} that is used in computing the correction factor it is known how many shells in series are to be used. For example if X_{4-8} is used then four shells in series with a total of 8 or more tube passes is required.

The complexity of this routine partially stems from a built-in prevention of division by zero. If a division by zero occurs the machine will overflow. For example, in Equation (14) a division by zero will occur when $(2/X) - 1 - R = \sqrt{R^2 + 1}$ or $R = 1$. In the first case this cannot occur for a one shell MTD correction factor greater than 0.8. Therefore when the machine discovers this case it develops an X parameter for two shell passes and $(2/X) - 1 - R$ will no longer equal $\sqrt{R^2 + 1}$. When $R = 1$, X_{n-2n} is calculated by Equation (11)⁵ and used in Equation (13).

SELECTION OF SIZE AND ARRANGEMENT

The function of the routine shown in Figure 4 is to keep track of the exchanger arrangement and the shell size.

By means of Equation (16) the preliminary surface is calculated. Then the surface per exchanger is calculated from Equation (17). In the first trial, one bank of exchangers is used. N_{ep} (number of exchangers in parallel) will be one. N_{es} (number in series) will be as determined from the MTD program.

After the number of tubes is calculated by Equation (18) the machine will search the standard 2 tube pass counts until a shell size with the same or more tubes is found.

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Some companies have the equipment to handle larger exchangers than others. Thus we must have some way of limiting the shell size. This is done by storing in the memory the 2 tube pass count for the largest acceptable shell size. Then whenever the shell size is changed the machine tests to make sure that the number of tubes is less than this maximum count (N_t max.). If the tube count is greater than N_t max. then a parallel bank of exchangers is added, thus reducing the shell size.

The first surface selected will be either the same or smaller than the final selection. The purpose of this is to eliminate the possibility of a selection that satisfies all conditions but is oversurfaced. This could happen if we started with a larger surface than the final selection. Starting with a smaller surface is accomplished by specifying in the input a U max. U max. is the maximum acceptable over-all heat transfer coefficient. If in doubt about what to specify, use a U that is abnormally high or use the reciprocal of the total fouling factor.

Exchanger shells that are smaller than 25-inch ID are manufactured from pipe. The tube counts used in the computer are based on the shell thickness shown in TEMA²—page 9. If the shell thickness calculated by Equation (19)⁷ exceeds the standard then the tube circle is reduced accordingly. When this is the case the new tube count is obtained by Equation (20). The case of shells larger than pipe size is simpler. For all pressures we can keep a standard tube circle and shell ID and let the OD fall where it will.

TUBE SIDE PRESSURE DROP

The program for the tube side pressure drop is illustrated in Figure 5. As can be seen it involves a relatively large amount of logic.

Each time the tube count or number of tube passes is changed the velocity is checked to make sure it is not too high. The maximum allowable velocity is calculated from Equation (23). If the fluid is clean the value to be used in the numerator will depend on the tube material used. A value of approximately 3500 can be used for admiralty tubes.

The Reynolds number is calculated and checked to see if the flow is turbulent or viscous. If the flow is viscous, Equation (27) is used. If the flow is turbulent, Equation (26) is used. Both of these equations are based on the Fanning equation. The friction factor incorporated in the viscous equation is simply $f = 16/Re$. The friction factor used for turbulent flow is $f = 0.048/Re^{0.2}$. A safety factor of 20 percent is used to take care of fouling and the effect of possible over tolerance of tube wall.

To take into consideration pressure drops on the tube side other than that inside the tube, Equation (25) is used. This gives an effective tube length which is inserted into Equation (25), or (27) if the flow is viscous.

This program is set up on the basis that the maximum number of tube passes is 12. If the calculated pressure drop is still under the allowable with 12 tube passes, the computer proceeds to the tube side heat transfer coefficient section.

TUBE SIDE FILM COEFFICIENT

For purposes of heat transfer we will consider the turbulent zone to be for a Reynolds number greater than 10,000. In this zone the Sieder and Tate⁶ equation is used.

When the Reynolds number is between 2100 and 10,000 it is called the transitional zone. In this zone one equation is not sufficient. Here we must resort to breaking the heat transfer data into intervals to fit the curves² as close as possible.

Equation (29) is used when the Reynolds number is less than 2100. Each rating that is computed in this zone should be examined carefully. This equation in some cases is conservative because it doesn't include the effects of natural circulation and turbulence at the tube ends.

Simplified equations are used for water and gas. These have the advantage of using relatively few physical properties. This saves time on compiling input data.

SHELL SIDE PRESSURE DROP

First the computer assembles the information necessary to compute the cross flow velocity and the baffle window velocity. From storage it brings the net free distance (NFD) for cross flow. The net free area (NFA) for baffle window flow is calculated from Equation (32).

The program is designed to discover special cases promptly. The special cases stem from the following:

- Low operating pressure on a vapor
- Abnormally high flow
- Abnormally low flow

The machine starts with maximum baffle pitch and maximum percent cut. The maximum allowable baffle pitch is that specified in TEMA² and will vary with tube OD. For most cases the maximum percent cut is approximately 45 percent. The machine starts with this baffling arrangement and calculates the pressure drop. If the pressure drop is excessive the machine will go into the divided flow portion of the routine. For the same pitch and cut, divided flow will reduce the shell side pressure drop by a factor of approximately 8. Thus the computer immediately tests for the first and second cases just discussed.

The machine tests for case 3 as follows: The machine starts reducing the baffle cut in 5 percent increments, calculating the pressure drop each time. When the baffle cut is reduced to 10 percent, the machine will add baffles one at a time. Baffles are added until minimum baffle pitch is encountered ($1/5$ of the shell ID down to 2 inches). When minimum baffle pitch is reached, the low flow case is discovered without trying every different possible combination of pitch and cut.

Without modification, this procedure, for a normal case, would give a low percent cut and wide baffle pitch. This type of baffling will also give a relatively low heat transfer coefficient for a given pressure drop.

For small computers, where memory space is at a premium, it is necessary to approximate the region of pitch and cut which will give optimum heat transfer for a given pressure drop. This is done by limiting the ratio of G_1/G_x to less than three.

In large computers, where memory space is not a problem, it is possible to choose a pitch and cut combination which gives the highest heat transfer. To arrive at the

optimum heat transfer coefficient use is made of the fact that the shell film coefficient is directly proportional to the product of G_x and G_1 . There is one combination of pitch and cut which will give a higher product of G_x and G_1 than any other. After the computer finds all the baffling combinations that meet pressure drop, the one which gives the highest velocity product is selected for use.

It is necessary to place a restriction on the shell side velocity. This is done in order to eliminate velocities that would set up damaging vibration. This is more of a problem in U-tube exchangers than it is in floating head and fixed tube sheet types. The velocity around the baffle is the most critical and usually has a higher value than the cross velocity. The velocity around the baffle is limited by Equation (36).

The shell side pressure drop equations are based on presentations of Chilton and Genereaux⁸ and Colburn⁹.

SHELL FILM COEFFICIENT

Figure 9 is the block diagram for the subroutine of the shell film coefficient. Equation (44) is based on work of Donohue.¹⁰ This is the best published correlation available at this time.

CALCULATION OF U AND SURFACE

This sub-routine is illustrated in Figure 10. The overall U is calculated from the sum of the heat transfer resistances shown in Equation (47). The calculated surface (48) is compared with the actual surface (49). If the actual surface is more, then the selection is printed out. If the surface is insufficient the computer returns to point A in Figure 4.

OUTPUT

Figure 11 illustrates the output format. Most of the information is of a mechanical nature. The film coefficients, Reynolds numbers and tube velocity are not necessary but come in handy in case of trouble.

MODIFICATIONS FOR SPECIAL CASES

Whenever the program is modified or added to, it is necessary to "debug" it. This is done by putting a problem in the computer and checking the new portion step by step. It is convenient to be able to specify to the input the tube passes, shell diameter and baffle pitch and cut in this case.

Sometimes the selection made by the computer is not the most economical. To account for this, it is necessary to be able to specify the new arrangement to the machine. For example if there is a very low flow it is sometimes cheaper to use two exchangers in series rather than one. The machine would normally use one exchanger. After this is done

it is necessary to be able to specify two exchangers in series to the computer input.

The program presented here can be modified to include such ratings as two pass shells, condensers, reboilers and heaters. By modification it can do fixed tube sheets, U-tubes, double pipe, fin tubes and kettles.

SYMBOLS USED

- A — Exchanger surface, sq. ft.
- B — Number of baffles
- C — Specific heat, Btu/(lb.) (F)
- d_i — Tube ID, in.
- d_o — Tube OD, in.
- F — MTD correction factor
- G_x — Tube mass velocity, lb/(ft.²) (sec.)
- G_x — Shell crossflow mass velocity, lb/(ft.²) (sec.)
- G_1 — Shell longitudinal mass velocity, lb/(ft.²) (sec.)
- G_m — Geometric mean velocity, lb/(ft.²) (sec.)
- GTD — Greater temperature difference, °F
- h_{i0} — Inside film coefficient, Btu/(hr.) (sq. ft.) (°F)
- h_o — Outside film coefficient, Btu/(hr.) (sq. ft.) (°F)
- ΔH — Enthalpy change, Btu/lb.
- k — Thermal conductivity, Btu/(hr.) (°F) (sq. ft./ft.)
- K — Characterization factor
- l — Tube pitch—tube OD, in.
- L — Tube length, ft.
- L' — Effective tube length, ft.
- LTD — Lesser temperature difference, °F
- MTD — Mean temperature difference, °F
- MTD_c — Mean temperature difference corrected, °F
- MW — Molecular weight
- n — Number of shell passes
- N — Number of rows in crossflow
- N_{es} — Number of exchangers in series
- N_{ep} — Number of exchangers in parallel
- NFA — Net free area, sq. in.
- NFD — Net free distance in.
- N_p — Number of tube passes
- N_t — Number of tubes
- p_o — Operating pressure, psi.
- P_d — Design pressure of shell, psi.
- P — Baffle pitch, in.
- ΔP_t — Tubeside pressure drop, psi.
- ΔP_x — Shell crossflow pressure drop, psi.
- ΔP_1 — Shell longitudinal pressure drop, psi.
- ΔP_s — Shell total pressure drop, psi.
- Q — Heat duty, Btu/hr.
- r_s — Shell inside radius, in.
- R — Parameter for MTD correction
- r_{f1} — Inside fouling (sq. ft.) (hr.) (°F)/Btu
- r_{f0} — Outside fouling (sq. ft.) (hr.) (°F)/Btu
- R_o — Reynolds number
- S.G. — Specific gravity
- t_a — Average temperature, °F
- Δt — Temperature range, °F
- T_{s1}, T_{s2} — Shell inlet and outlet temperature, °F
- T_{c1}, T_{c2} — Channel inlet and outlet temperature, °F
- T_k — Shell thickness, in.
- T.C. — Tube circle or bundle diameter, in.
- U — Over-all heat transfer coefficient, Btu/(hr.) (sq. ft.) (°F)

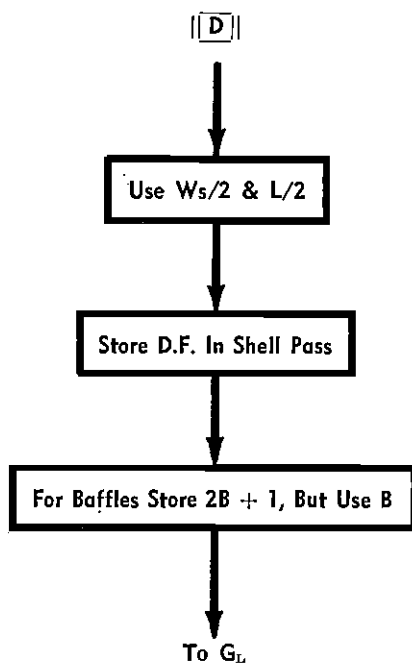
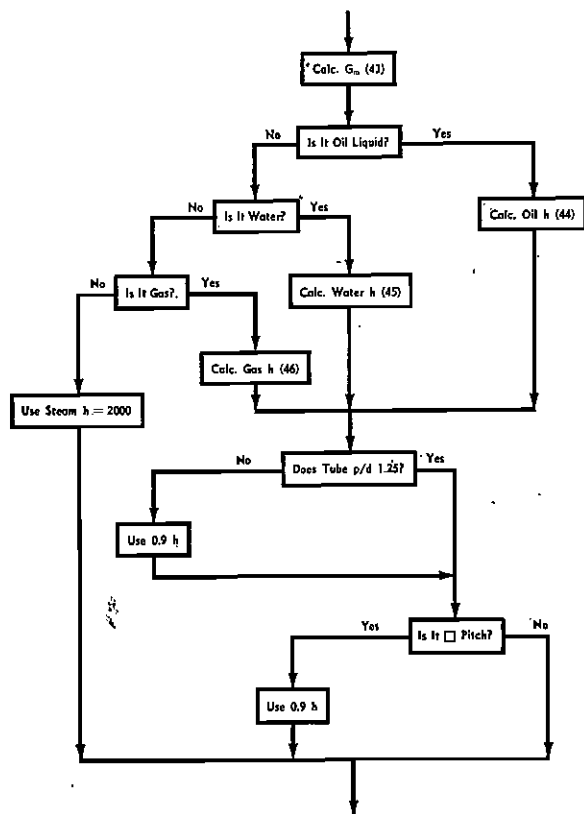


FIGURE 8—If the pressure drop in the shell is excessive, the machine will go into the divided flow portion of the routine shown here.



$$G_m = \sqrt{(G_x)(G_L)} \quad (43)$$

$$h = \frac{64 G_m^{0.6}}{d_o^{0.4} \mu^{0.6}} \cdot K \left(\frac{C\mu}{K} \right)^{1/4} \left(\frac{\mu}{\mu_w} \right)^{0.14} \quad (44)$$

$$\text{Water } h = 247 \frac{(1 + 0.0067 t_a)}{d_o^{0.4} \rho^{0.6}} G_m^{0.6} \quad (45)$$

$$\text{Gas } h = 29 \frac{CG_m^{0.6}}{d_o^{0.4}} \quad (46)$$

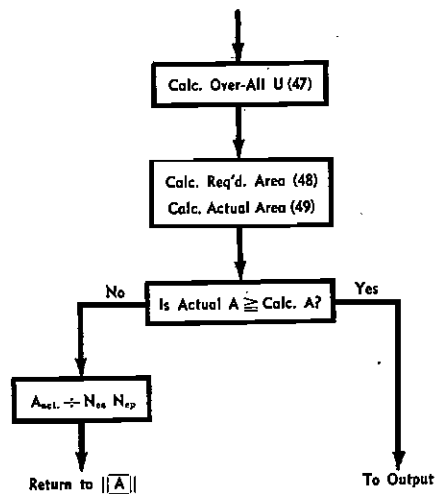
FIGURE 9—The subroutine of the shell film coefficient is based on work of Donohue.¹⁰

FIGURE 11—The film coefficients, Reynolds numbers and tube velocity are not necessary in the output form, but they come in handy in case of trouble.

- V — Velocity, ft./sec.
- W — Flow rate, lb./hr.
- X — Variable for MTD correction
- Z — Compressibility factor
- μ — Viscosity, centipoise
- μ_w — Viscosity at the wall, centipoise
- ρ — Density, lbs./cu. ft.

LITERATURE CITED

¹ Holcomb, D. E., and Brown, G. G., *Ind. Eng. Chem.*, 34, 595 (1942).
² Standards of TEMA, Third Edition, 1952, and Addenda, October, 1954.
³ Underwood, A. J. V., *Journal, Institute of Petroleum Technologists*, 20, 145-58 (1934).
⁴ Bowman, R. A., Mueller, A. C., and Nagle, W. M., *Trans. Am. Soc. Mech. Engrs.*, 62, 283-94 (1940).
⁵ Bowman, R. A., *Ind. Eng. Chem.*, 28, 541-44 (1936).
⁶ Sieder, E. N., and Tate, G. E., *Ind. Eng. Chem.*, 28, 1429-34 (1936).
⁷ *ASME Code UPV*, 9 (1959).
⁸ Chilton and Genereaux, *Trans. of A.I.Ch.E.*, 29, 161 (1933).
⁹ Colburn, *Eng. Bull. Purdue Univ. Research Series No. 84*.
¹⁰ Donohue, D. A., *Ind. Eng. Chem.*, 41, 2499-2511 (1949).



$$U = 1/h_o + 1/h_{i_o} + r_a \quad (47)$$

$$A_{calc.} = \frac{Q}{MTD_o U} \quad (48)$$

$$\text{Actual } A = (N_{es} N_{ep} N_t L) (\text{Sq. In./Ft.}) \quad (49)$$

FIGURE 10—The overall U is calculated from the sum of the heat transfer resistances. Point A refers back to Figure 4.

No. of exchangers and arrangement	_____ parallel _____ series
Shell I.D. and length	_____
Surface	_____ each _____ total
Over-all transfer coefficient	_____ calc. _____ actual
Corrected MTD	_____
	SHELL TUBE
No. of passes	_____
Calc. pressure drop	_____
Film coefficient	_____
Reynolds number	_____
Velocity	_____
No. of tubes	_____
No. of baffles	_____ pitch _____ cut _____

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