Correction Factor for Complex H.E (F)

For more complex H.E. such as those involving multiple tubes, several shell passes or cross flow, determination of the LMTD is so difficult, thus the heat-transfer equation then takes the form

$$q = AUF\Delta T_{LM}$$

F the correction factor.

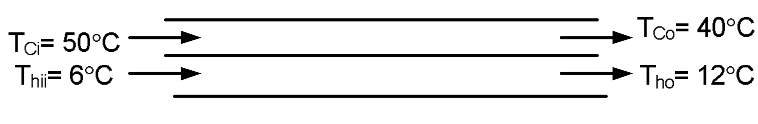
$$F = 1 \qquad For \begin{cases} \text{a) condensation or boiling (evaporation)} \\ b) \text{ counter flow double-pipe heat exchanger} \end{cases}$$

The values of correction factor can be found in Figures 10.8 to 10.11, for one two, two four, cross flow (both fluid unmixed) and cross flow (one fluid mixed and the other unmixed), respectively.

Example: In a food pressing plate a brine solution is heated from 6°C to 12°C in a double pipe H.E. by water interring at 50°C and leaving at 40°C at the rate of 0.166kg/s, if the overall heat transfer coefficient is 850 W/m^2.K. What heat exchanger area is required for a) parallel or co-current flow, b) counter current flow?

Solution:

a) Co-Current flow



$$\Delta T_1 = 50 - 6 = 44$$
$$\Delta T_2 = 40 - 12 = 28$$

$$q = AUF\Delta T_{LM} \Rightarrow A = q/UF\Delta T_{LM}$$

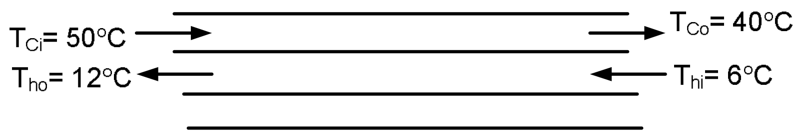
$$\Delta T_{LM} = \frac{44-28}{\ln\frac{44}{28}} = 35.4°\text{C}$$

Cp for water is 4.18 kJ/kg.K.

$$\therefore \quad q = mCp\Delta T = 0.166 \times 4180 \times (50-40) = 6.967 \times 10^3 W$$

$$\therefore \quad A = \frac{6.967 \times 10^3}{850 \times 35.4} = 0.231 m^2$$

b) Counter current



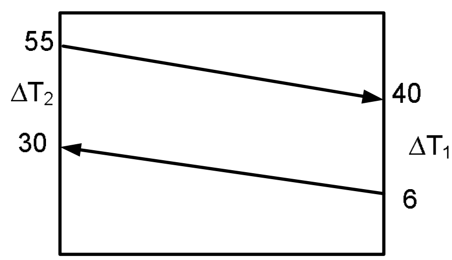
$$\Delta T_1 = 50 - 12 = 38$$
$$\Delta T_2 = 40 - 6 = 34$$

$$\Delta T_{LM} = \frac{38 - 34}{\ln \frac{38}{34}} = 35.96°C$$

$$\Rightarrow \; A = 0.228 m^2$$

Example: a brine solution is heated from 6°C to 30°C in a one shell pass (hot water) two tubes pass (brine) H.E. the hot water inters at 55°C and exists at 40°C. the water flow rate is 0.25kg/s and the overall heat transfer coefficient is 900 W/m^2.K. What heat exchanger area is required?

Solution:



$$\Delta T_1 = 55 - 30 = 25$$
$$\Delta T_2 = 40 - 6 = 34$$

$$q = AUF\Delta T_{LM} \;\Rightarrow A = q/UF\Delta T_{LM}, \qquad \Delta T_{LM} = \frac{34 - 25}{\ln \frac{34}{25}} = 29.27°C$$

from Figure 10.8, $P = 0.49,\ R = 0.625 \;\Rightarrow\; F = 0.92$

$$q = mCp\Delta T = 0.25 \times 4181 \times (55\text{-}40) = 15678 W$$

$$\therefore\; A = 0.647 m^2$$

Fouling Factors

When deposits are present on the inside and outside surface of tubes, the thermal resistance will increase resulting in decreased performance. This added resistance is accounted by a fouling factor or a fouling resistance R_f, which must be included along with the other thermal resistances making up the overall heat-transfer coefficient.

$$R_f = \frac{1}{U_{\text{dirty}}} - \frac{1}{U_{\text{clean}}}$$

An abbreviated list of recommended values of the fouling factor for various fluids is given in Table 10-2.

Example 10.3 about fouling factor.

The effects of fouling factors on both the inner and the outer surfaces of the tube should be taken into accounts. For un unfinned shell and tube H.E. the overall H.T. coefficient can be expressed as

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R = \frac{1}{h_iA_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_oA_o}$$

where $R_{f,i}$ and $R_{f,o}$ are the fouling factors at those surfaces.

Design of Shell-and-Tube Heat Exchanger

EXAMPLE 10-6

Water at the rate of 30,000 lb_m/h [3.783 kg/s] is heated from 100 to 130°F [37.78 to 54.44°C] in a shell-and-tube heat exchanger. On the shell side one pass is used with water as the heating fluid, 15,000 lb_m/h [1.892 kg/s], entering the exchanger at 200°F [93.33°C]. The overall heat-transfer coefficient is 250 Btu/h · ft^2 · °F [1419 W/m^2 · °C], and the average water velocity in the $\frac{3}{4}$-in [1.905-cm] diameter tubes is 1.2 ft/s [0.366 m/s]. Because of space limitations, the tube length must not be longer than 8 ft [2.438 m]. Calculate the number of tube passes, the number of tubes per pass, and the length of the tubes, consistent with this restriction.

■ Solution

We first assume one tube pass and check to see if it satisfies the conditions of this problem. The exit temperature of the hot water is calculated from

$$q = \dot{m}_c c_c \,\Delta T_c = \dot{m}_h c_h \,\Delta T_h$$

$$\Delta T_h = \frac{(30{,}000)(1)(130-100)}{(15{,}000)(1)} = 60°\text{F} = 33.33°\text{C} \qquad [a]$$

so

$$T_{h,\text{exit}} = 93.33 - 33.33 = 60°\text{C}$$

The total required heat transfer is obtained from Equation (a) for the cold fluid:

$$q = (3.783)(4182)(54.44 - 37.78) = 263.6\ \text{kW} \quad [8.08 \times 10^5\ \text{Btu/h}]$$

For a counterflow exchanger, with the required temperature

$$\text{LMTD} = \Delta T_m = \frac{(93.33 - 54.44) - (60 - 37.78)}{\ln[(93.33 - 54.44)/(60 - 37.78)]} = 29.78°\text{C}$$

$$q = UA\,\Delta T_m$$

$$A = \frac{2.636 \times 10^5}{(1419)(29.78)} = 6.238\ \text{m}^2 \quad [67.1\ \text{ft}^2] \qquad [b]$$

Using the average water velocity in the tubes and the flow rate, we calculate the total flow area with

$$\dot{m}_c = \rho A u$$

$$A = \frac{3.783}{(1000)(0.366)} = 0.01034\ \text{m}^2 \qquad [c]$$

This area is the product of the number of tubes and the flow area per tube:

$$0.01034 = n\frac{\pi d^2}{4}$$

$$n = \frac{(0.01034)(4)}{\pi(0.01905)^2} = 36.3$$

or $n = 36$ tubes. The surface area per tube per meter of length is

$$\pi d = \pi(0.01905) = 0.0598\ \text{m}^2/\text{tube}\cdot\text{m}$$

We recall that the total surface area required for a one-tube-pass exchanger was calculated in Equation (b) as 6.238 m^2. We may thus compute the length of tube for this type of exchanger from

$$n\pi d\,L = 6.238$$

$$L = \frac{6.238}{(36)(0.0598)} = 2.898\ \text{m}$$

This length is greater than the allowable 2.438 m, so we must use more than one tube pass. When we increase the number of passes, we correspondingly increase the total surface area required because of the reduction in LMTD caused by the correction factor F. We next try two tube passes. From Figure 10-8, $F = 0.88$, and thus

$$A_{\text{total}} = \frac{q}{UF\Delta T_m} = \frac{2.636 \times 10^5}{(1419)(0.88)(29.78)} = 7.089\ \text{m}^2$$

The number of tubes per pass is still 36 because of the velocity requirement. For the two-tube-pass exchanger the total surface area is now related to the length by

$$A_{\text{total}} = 2n\pi d\,L$$

so that

$$L = \frac{7.089}{(2)(36)(0.0598)} = 1.646\ \text{m} \quad [5.4\ \text{ft}]$$

Also, examples 10.4, 5, 7 and 8.

Figure 10-8 | Correction-factor plot for exchanger with one shell pass and two, four, or any multiple of tube passes.

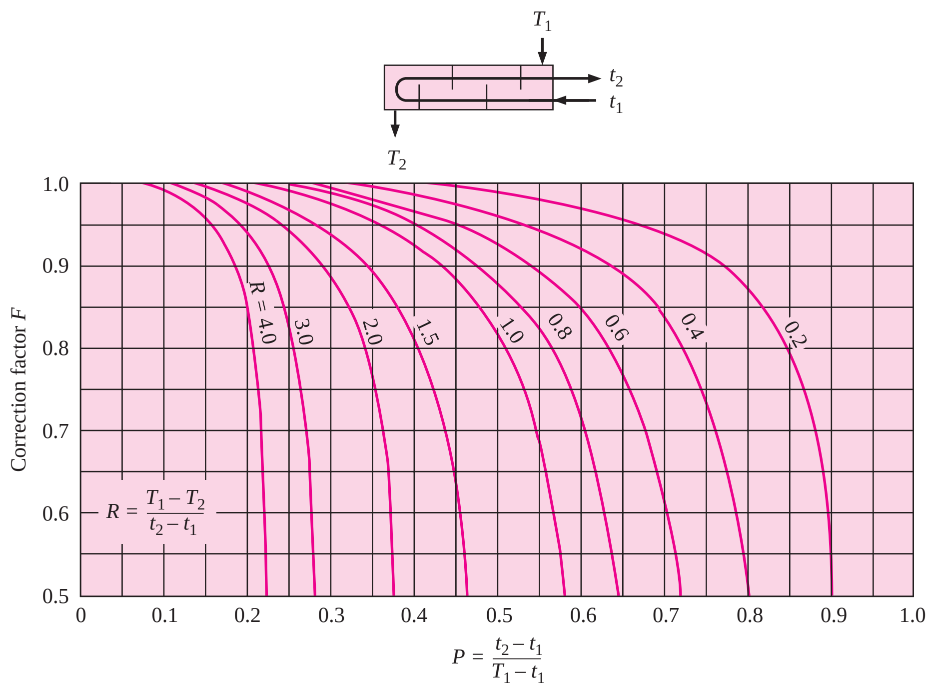


Figure 10-9 | Correction-factor plot for exchanger with two shell passes and four, eight, or any multiple of tube passes.

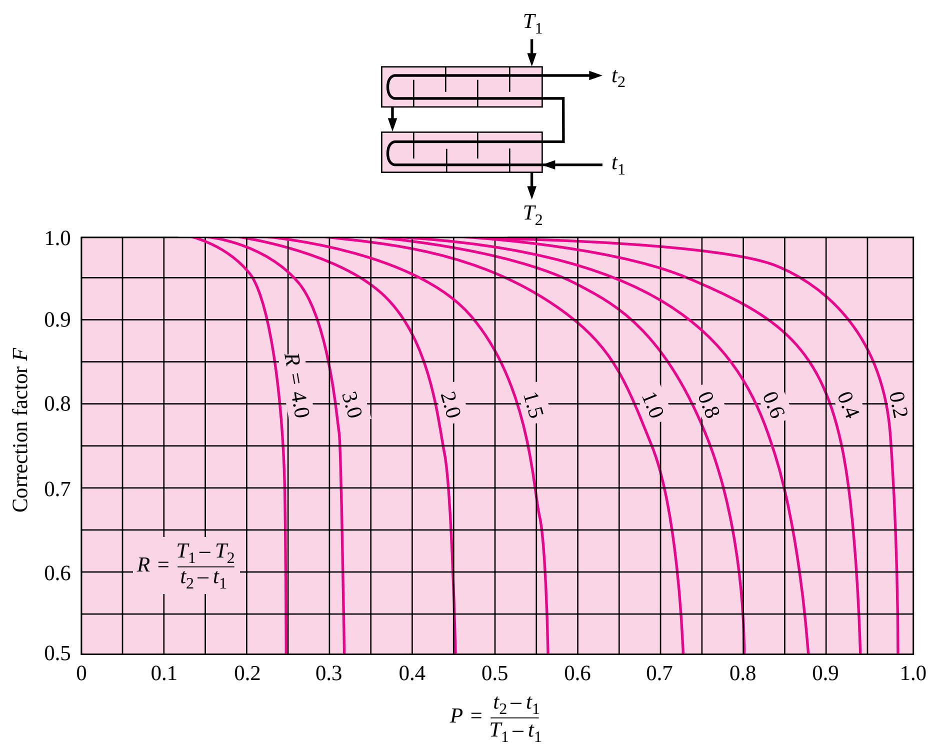
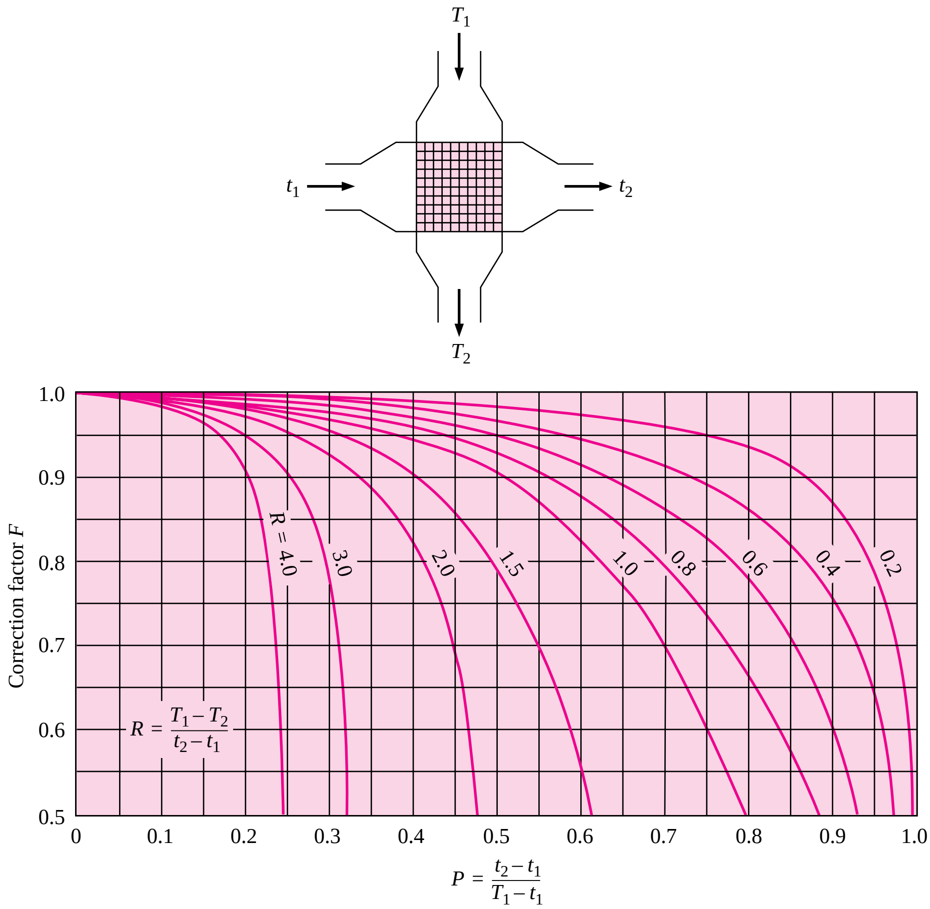


Figure 10-10 | Correction-factor plot for single-pass cross-flow exchanger, both fluids unmixed.



This temperature difference is called the *log mean temperature difference* (LMTD). Stated verbally, it is the temperature difference at one end of the heat exchanger less the temperature difference at the other end of the exchanger divided by the natural logarithm of the ratio of these two temperature differences. It is left as an exercise for the reader to show that this relation may also be used to calculate the LMTDs for counterflow conditions.

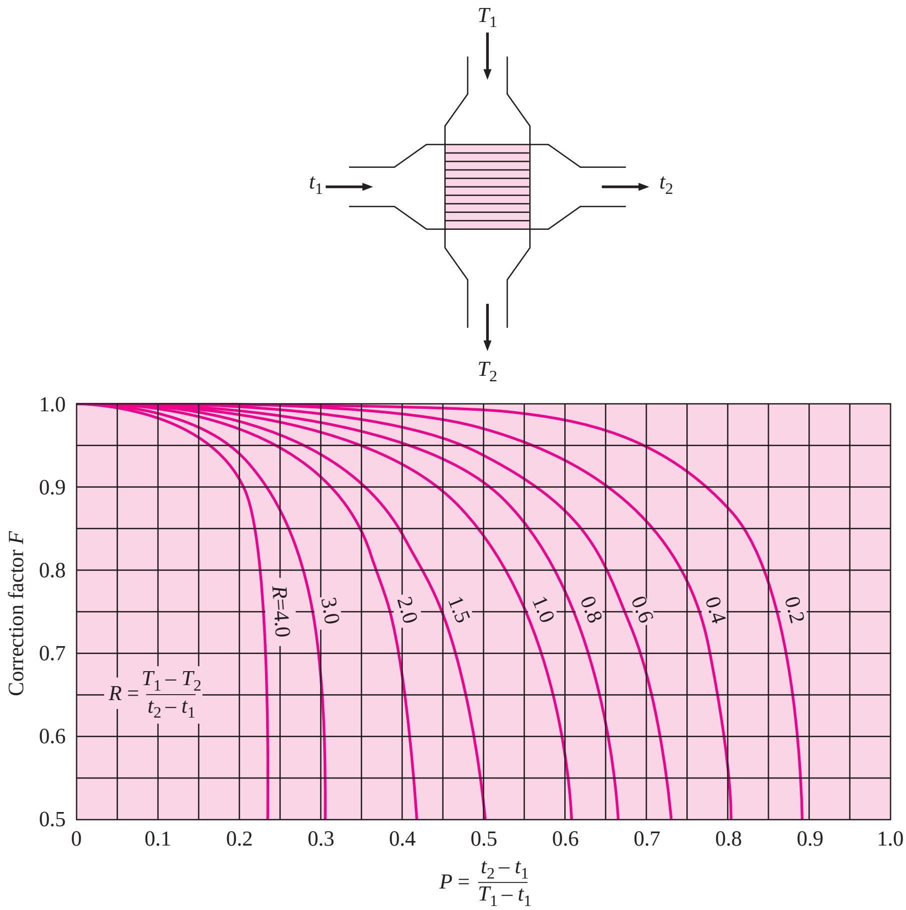
The above derivation for LMTD involves two important assumptions: (1) the fluid specific heats do not vary with temperature, and (2) the convection heat-transfer coefficients are constant throughout the heat exchanger. The second assumption is usually the more serious one because of entrance effects, fluid viscosity, and thermal-conductivity changes, etc. Numerical methods must normally be employed to correct for these effects. Section 10-8 describes one way of performing a variable-properties analysis.

If a heat exchanger other than the double-pipe type is used, the heat transfer is calculated by using a correction factor applied to the LMTD ***for a counterflow double-pipe arrangement with the same hot and cold fluid temperatures.*** The heat-transfer equation then takes the form

$$q = UAF\Delta T_m \qquad \textbf{[10-13]}$$

Values of the correction factor F according to Reference 4 are plotted in Figures 10-8 to 10-11 for several different types of heat exchangers. When a phase change is involved, as

Figure 10-11 | Correction-factor plot for single-pass cross-flow exchanger, one fluid mixed, the other unmixed.



in condensation or boiling (evaporation), the fluid normally remains at essentially constant temperature and the relations are simplified. For this condition, P or R becomes zero and we obtain

$$F = 1.0 \qquad \text{for boiling or condensation}$$

Examples 10-4 to 10-8 illustrate the use of the LMTD method for calculation of heat-exchanger performance.

EXAMPLE 10-4 Calculation of Heat-Exchanger Size from Known Temperatures

Water at the rate of 68 kg/min is heated from 35 to 75°C by an oil having a specific heat of 1.9 kJ/kg · °C. The fluids are used in a counterflow double-pipe heat exchanger, and the oil enters the exchanger at 110°C and leaves at 75°C. The overall heat-transfer coefficient is 320 W/m^2 · °C. Calculate the heat-exchanger area.

■ Solution

The total heat transfer is determined from the energy absorbed by the water:

$$q = \dot{m}_w c_w \Delta T_w = (68)(4180)(75 - 35) = 11.37 \text{ MJ/min} \qquad [a]$$

$$= 189.5 \text{ kW} \qquad [6.47 \times 10^5 \text{ Btu/h}]$$