

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.

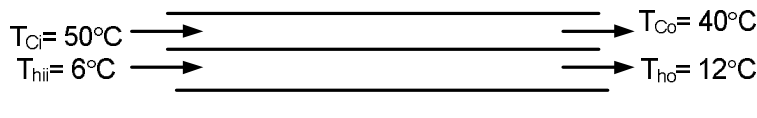
$$F = 1 \quad \text{For} \begin{cases} \text{a) condensation or boiling (evaporation)} \\ \text{b) counter flow double-pipe heat exchanger} \end{cases}$$

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/m².K. What heat exchanger area is required for a) parallel or co-current flow, b) counter current flow?

Solution:

a) Co-Current flow



$$\Delta T_1 = 50 - 6 = 44$$

$$\Delta T_2 = 40 - 12 = 28$$

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

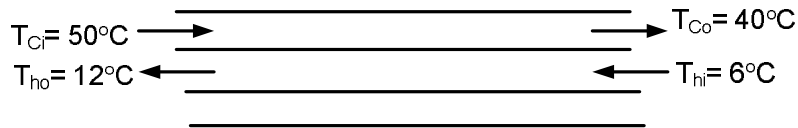
$$\Delta T_{LM} = \frac{44 - 28}{\ln \frac{44}{28}} = 35.4^\circ\text{C}$$

Cp for water is 4.18 kJ/kg.K.

$$\therefore q = mC_p\Delta T = 0.166 \times 4180 \times (50 - 40) = 6.967 \times 10^3 \text{ W}$$

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

b) Counter current



$$\Delta T_1 = 50 - 12 = 38$$

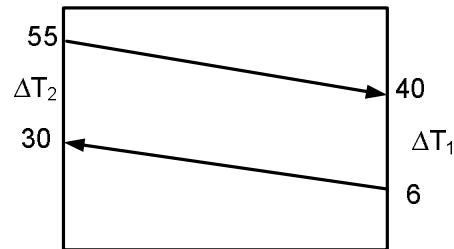
$$\Delta T_2 = 40 - 6 = 34$$

$$\Delta T_{LM} = \frac{38 - 34}{\ln \frac{38}{34}} = 35.96^\circ\text{C}$$

$$\Rightarrow A = 0.228\text{m}^2$$

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 enters at 55°C and exits at 40°C . the water flow rate is 0.25kg/s and the overall heat transfer coefficient is $900\text{ W/m}^2\cdot\text{K}$. What heat exchanger area is required?

Solution:



$$\Delta T_1 = 55 - 30 = 25$$

$$\Delta T_2 = 40 - 6 = 34$$

$$q = AUF\Delta T_{LM} \Rightarrow A = q/UF\Delta T_{LM}, \quad \Delta T_{LM} = \frac{34 - 25}{\ln \frac{34}{25}} = 29.27^\circ\text{C}$$

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

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

$$\therefore A = 0.647\text{m}^2$$

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 an unfinned shell and tube H.E. the overall H.T. coefficient can be expressed as

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi k L} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

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 · ft² · °F [1419 W/m² · °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

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

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

so

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

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

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

$$q = UA \Delta T_m$$

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

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

$$\dot{m}_c = \rho Au$$

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

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.