Chapter 11 Supplemental Material

11S.1
Log Mean Temperature Difference Method for Multipass and Cross-Flow Heat Exchangers

Although flow conditions are more complicated in multipass and cross-flow heat exchangers, Equations 11.6, 11.7, 11.14, and 11.15 may still be used if the following modification is made to the log mean temperature difference [1]:

$$\Delta T_{\mathrm{lm}} = F\,\Delta T_{\mathrm{lm,CF}} \tag{11S.1}$$

That is, the appropriate form of ΔT_{lm} is obtained by applying a correction factor to the value of ΔT_{lm} that would be computed *under the assumption of counterflow conditions.* Hence from Equation 11.17, $\Delta T_1 = T_{h,i} - T_{c,o}$ and $\Delta T_2 = T_{h,o} - T_{c,i}$.

Algebraic expressions for the correction factor F have been developed for various shell-and-tube and cross-flow heat exchanger configurations [1–3], and the results may be represented graphically. Selected results are shown in Figures 11S.1 through 11S.4 for common heat exchanger configurations. The notation (T, t) is used to specify the fluid temperatures, with the variable t always assigned to the tube-side

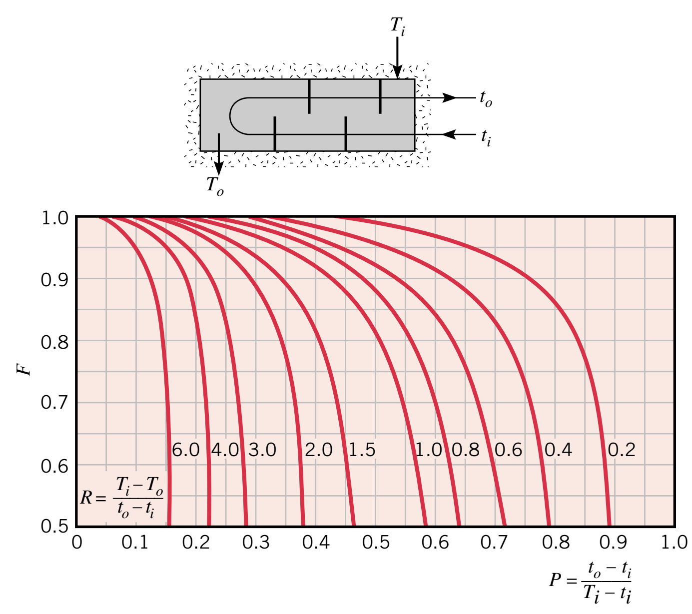


FIGURE 11S.1 Correction factor for a shell-and-tube heat exchanger with one shell and any multiple of two tube passes (two, four, etc. tube passes).

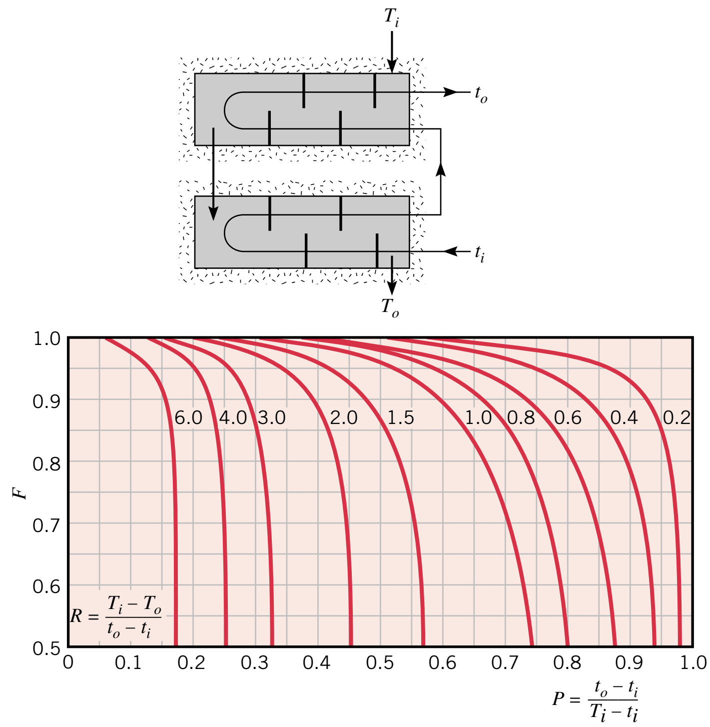


FIGURE 11S.2 Correction factor for a shell-and-tube heat exchanger with two shell passes and any multiple of four tube passes (four, eight, etc. tube passes).

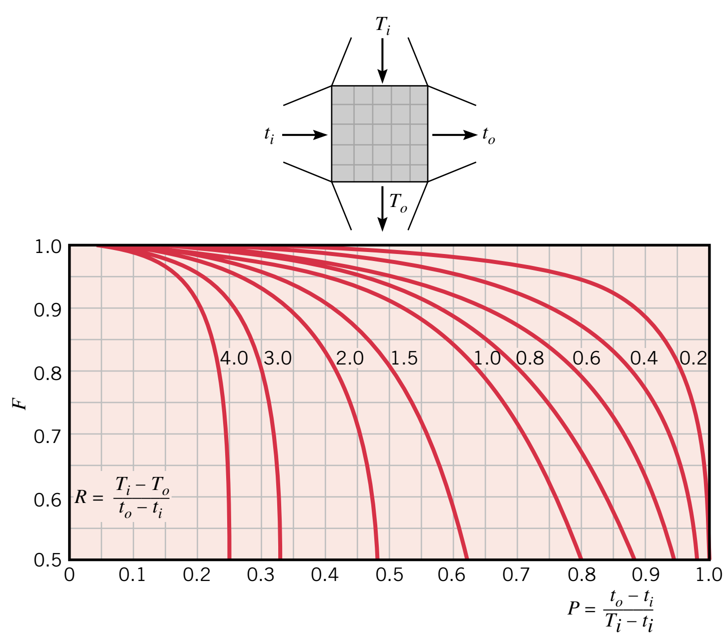


FIGURE 11S.3 Correction factor for a single-pass, cross-flow heat exchanger with both fluids unmixed.

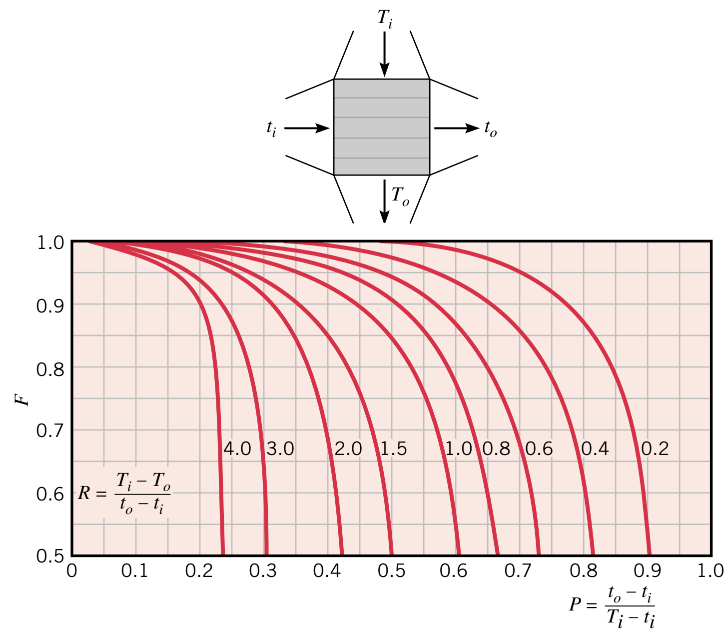


FIGURE 11S.4 Correction factor for a single-pass, cross-flow heat exchanger with one fluid mixed and the other unmixed.

fluid. With this convention it does not matter whether the hot fluid or the cold fluid flows through the shell or the tubes. An important implication of Figures 11S.1 through 11S.4 is that, *if the temperature change of one fluid is negligible,* either P or R is zero and F is 1. *Hence heat exchanger behavior is independent of the specific configuration.* Such would be the case if one of the fluids underwent a phase change.

EXAMPLE 11S.1

A shell-and-tube heat exchanger must be designed to heat 2.5 kg/s of water from 15 to 85°C. The heating is to be accomplished by passing hot engine oil, which is available at 160°C, through the shell side of the exchanger. The oil is known to provide an average convection coefficient of $h_o = 400\ \text{W/m}^2 \cdot \text{K}$ on the outside of the tubes. Ten tubes pass the water through the shell. Each tube is thin walled, of diameter $D = 25$ mm, and makes eight passes through the shell. If the oil leaves the exchanger at 100°C, what is its flow rate? How long must the tubes be to accomplish the desired heating?

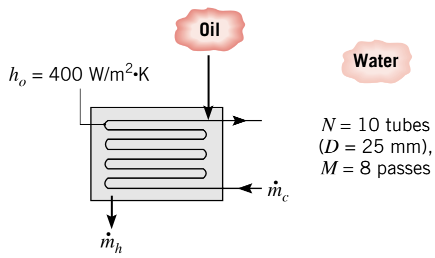
SOLUTION

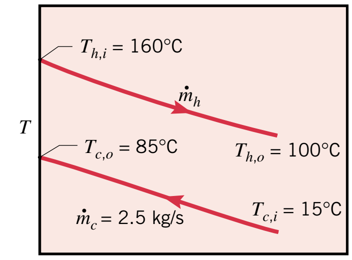
Known: Fluid inlet and outlet temperatures for a shell-and-tube heat exchanger with 10 tubes making eight passes.

Find:

1. Oil flow rate required to achieve specified outlet temperature.
2. Tube length required to achieve specified water heating.

Schematic:





Assumptions:

1. Negligible heat loss to the surroundings and kinetic and potential energy changes.
2. Constant properties.
3. Negligible tube wall thermal resistance and fouling effects.
4. Fully developed water flow in tubes.

Properties: Table A.5, unused engine oil ($\overline{T}_h = 130°\text{C}$): $c_p = 2350$ J/kg · K. Table A.6, water ($\overline{T}_c = 50°\text{C}$): $c_p = 4181$ J/kg · K, $\mu = 548 \times 10^{-6}$ N · s/m^2, $k = 0.643$ W/m · K, $Pr = 3.56$.

Analysis:

1. From the overall energy balance, Equation 11.7b, the heat transfer required of the exchanger is

$$q = \dot{m}_c c_{p,c}(T_{c,o} - T_{c,i}) = 2.5\ \text{kg/s} \times 4181\ \text{J/kg} \cdot \text{K}\ (85 - 15)°\text{C}$$

$$q = 7.317 \times 10^5\ \text{W}$$

Hence, from Equation 11.6b,

$$\dot{m}_h = \frac{q}{c_{p,h}(T_{h,i} - T_{h,o})} = \frac{7.317 \times 10^5\ \text{W}}{2350\ \text{J/kg} \cdot \text{K} \times (160 - 100)°\text{C}} = 5.19\ \text{kg/s} \qquad \triangleleft$$

2. The required tube length may be obtained from Equations 11.14 and 11S.1, where

$$q = UAF\,\Delta T_{\text{lm, CF}}$$

From Equation 11.5,

$$U = \frac{1}{(1/h_i) + (1/h_o)}$$

where h_i may be obtained by first calculating Re_D. With $\dot{m}_1 \equiv \dot{m}_c/N = 0.25$ kg/s defined as the water flow rate per tube, Equation 8.6 yields

$$Re_D = \frac{4\dot{m}_1}{\pi D \mu} = \frac{4 \times 0.25\ \text{kg/s}}{\pi\,(0.025\ \text{m})\, 548 \times 10^{-6}\ \text{kg/s} \cdot \text{m}} = 23{,}234$$

Hence the water flow is turbulent, and from Equation 8.60

$$Nu_D = 0.023 Re_D^{4/5}\, Pr^{0.4} = 0.023(23{,}234)^{4/5}(3.56)^{0.4} = 119$$

$$h_i = \frac{k}{D} Nu_D = \frac{0.643\ \mathrm{W/m \cdot K}}{0.025\ \mathrm{m}} 119 = 3061\ \mathrm{W/m^2 \cdot K}$$

Hence

$$U = \frac{1}{(1/400) + (1/3061)} = 354\ \mathrm{W/m^2 \cdot K}$$

The correction factor F may be obtained from Figure 11S.1, where

$$R = \frac{160 - 100}{85 - 15} = 0.86 \qquad P = \frac{85 - 15}{160 - 15} = 0.48$$

Hence $F \approx 0.87$. From Equations 11.15 and 11.17, it follows that

$$\Delta T_{\mathrm{lm,CF}} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln[(T_{h,i} - T_{c,o})/(T_{h,o} - T_{c,i})]} = \frac{75 - 85}{\ln(75/85)} = 79.9^\circ\mathrm{C}$$

Hence, since $A = N\pi DL$, where $N = 10$ is the number of tubes,

$$L = \frac{q}{UN\pi DF\, \Delta T_{\mathrm{lm,CF}}} = \frac{7.317 \times 10^5\ \mathrm{W}}{354\ \mathrm{W/m^2 \cdot K} \times 10\pi(0.025\ \mathrm{m})0.87(79.9^\circ\mathrm{C})}$$

$$L = 37.9\ \mathrm{m}$$ ◁

Comments:

1. With $(L/D) = 37.9\ \mathrm{m}/0.025\ \mathrm{m} = 1516$, the assumption of fully developed conditions throughout the tube is justified.
2. With eight passes, the shell length is approximately $L/M = 4.7$ m.

References

1. Bowman, R. A., A. C. Mueller, and W. M. Nagle, *Trans. ASME*, **62**, 283, 1940.
2. *Standards of the Tubular Exchange Manufacturers Association*, 6th ed., Tubular Exchange Manufacturers Association, New York, 1978.
3. Jakob, M., *Heat Transfer*, Vol. 2, Wiley, New York, 1957.

Problems

Log Mean Temperature Difference Method

11S.1 Solve Problem 11.9 using the LMTD method.

11S.2 Solve Problem 11.10 using the LMTD method.

11S.3 Solve Problem 11.14 using the LMTD method.

11S.4 Solve Problem 11.15 using the LMTD method.

11S.5 Solve Problem 11.23 using the LMTD method.

11S.6 Solve Problem 11.32 using the LMTD method.

11S.7 Solve Problem 11.44 using the LMTD method.

11S.8 Solve Problem 11.47 using the LMTD method.

11S.9 Solve Problem 11.52 using the LMTD method.

11S.10 Solve Problem 11.59 using the LMTD method.

11S.11 Solve Problem 11.70 using the LMTD method.