New Problems Chapter 16

16.2-4. ***Heat Transfer Area Needed.*** Determine the heat transfer surface area needed for a heat exchanger that heats 10 gal/min of ethanol from 25°C to 50°C using water that enters at 95°C and at a rate of 0.3 kg/s. The overall heat transfer coefficient is $U_o = 500\dfrac{W}{m^2 \cdot K}$.

a) For a single pass cross-flow exchanger where the shell-side is mixed and the other fluid unmixed.

b) For a single pass cross-flow exchanger where both fluids are mixed.

16.3-2. **Outlet temperatures of an existing heat exchanger.** Determine the outlet temperatures from a counterflow heat exchanger that is used to heat 2 kg/s of ethanol $\left(Cp = 2.7\dfrac{kJ}{kg \cdot K}\right)$ at 298K with water $\left(Cp = 4.2\dfrac{kJ}{kg \cdot K}\right)$ that enters at 363.15K and at a rate of 0.4 kg/s. The overall heat transfer coefficient is $U_o = 500\dfrac{W}{m^2 \cdot K}$ and the area of the exchanger is 1.4 m2. Use equation 16.3-12 except there is a Typo.

Equation 16.3-2 should read $\varepsilon = \dfrac{1-\exp\left[\dfrac{-UA}{C_{\min}}\left(1-\dfrac{C_{\min}}{C_{\max}}\right)\right]}{1-\dfrac{C_{\min}}{C_{\max}}\exp\left[\dfrac{-UA}{C_{\min}}\left(1-\dfrac{C_{\min}}{C_{\max}}\right)\right]}$ it is missing a minus sign on the denominator.

16.4-1. **Overall U values with fouling factors**. You have double pipe heat exchanger where the inside pipe is 2in schedule 80 made of copper that is 5m long. It has an inside heat transfer coefficient of $\left(h_i = 2200\dfrac{W}{m^2 \cdot K}\right)$ a thermal conductivity of, $\left(k = 380\dfrac{W}{m \cdot K}\right)$ and outside heat transfer coefficient of $\left(h_o = 3000\dfrac{W}{m^2 \cdot K}\right)$. Both sides of the pipe have been exposed to city water and have developed fouling/scaling. What is the new overall heat transfer coefficient (Uo) caused by the fouling and by what percent did the thermal resistance increase due to the fouling.

16.4-2. **Find the fouling factor:** Under initial design conditions, your double pipe heat exchanger was to transfer 10000 kW of energy to your process stream. After months of running, you see a drop of energy transfer to 8500 kW and you assume the drop is caused by fouling on the outside of the inner pipe. What is the fouling factor $h_d \text{ in } \left(\dfrac{W}{m^2 \cdot K}\right)$ given the following? Assume negligible area change (0.63m2) due to the fouling (very thin), and a constant LMTD = 40K (not realistic but a good start).

16.5-1. **Double Pipe exchanger design**: After fermentation a mixture of ethanol and water is sent to a distillation column. At the top of the distillation column a 95% ethanol solution at 65°C is produced at a flow rate of 3.5 kg/s. Your job is to design a double pipe heat exchanger that will cool the 95% ethanol mixture to 40°C by using cooling water that is available at 10°C. Assume a 5°C approach to the inlet, 95% ethanol solution and only use schedule 40 pipe. Do not do viscosity corrections for heat transfer coefficients and the 95% ethanol solution will be pumped in the inside pipe.

The properties of the 95% ethanol are (assume constant over temperature range):

$$k = 0.20\frac{W}{m\cdot K},\ \rho = 789\frac{kg}{m^3},\ \mu = 1.20\cdot 10^{-3}\,Pa\cdot s,\ Cp = 2.6\cdot\frac{kJ}{kg\cdot K}$$

The fouling factors are:

Cooling Water: $17.6\times 10^{-5}\,\frac{m^2\cdot K}{W}$

Ethanol: $8\times 10^{-5}\,\frac{m^2\cdot K}{W}$

16.5-2. **Double Pipe exchanger design** After a solvent extraction step Benzene at 3.0 kg/s and 80°C needs to be cooled in a double pipe heat exchanger that will cool the Benzene to 40°C. You have cooling water that is available at 5°C. Assume a 55°C (cooling water limitations) approach to the inlet/Benzene and only use schedule 40 pipe. Do not do viscosity corrections for heat transfer coefficients and Benzene will be pumped in the inside pipe.

The properties of the Benzene are (assume constant over temperature range):

$$k = 0.15\frac{W}{m\cdot K},\ \rho = 879\frac{kg}{m^3},\ \mu = 0.36cP,\ Cp = 1.9\cdot\frac{kJ}{kg\cdot K}$$

The fouling factors are:

Cooling Water: $17.6\times 10^{-5}\,\frac{m^2\cdot K}{W}$

Benzene: $8\times 10^{-5}\,\frac{m^2\cdot K}{W}$