ChE 306: HEAT TRANSFER
FALL 2010
Homework #9: Ch 10 & 11
(80 points + 15 bonus points)
DUE: FRIDAY, NOVEMBER 12

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1. A 15 ^oC copper rectangular surface measuring 0.6 m by 1.5 m and coated with Rain-X is oriented horizontally above a pool of saturated steam kept at a pressure of 0.51 bars so that it condenses in a dropwise form.
A. What is the rate of heat transfer from the vapor to the copper surface? (W)
B. How fast does liquid water form (use h_{fg}')? (kg/s)
C. If the Rain-X were stripped away, would the heat transfer rate increase, decrease or stay the same? Why?

2. A fire-tube boiler uses the hot products of a combustion reaction (flowing in the tubes) to boil water flowing over the outside of the tubes. When the boiler was first installed U was found to be 400 W/m^2-K. After one year, both sides of the tubes have become fouled. $R_{f,i}$" = 0.0015 and $R_{f,o}$" = 0.0005 m^2-K/W. Should the boiler be cleaned to remove the fouling? You may consider the resistance to conduction through the pipe to be negligible.

3. Work Incropera and DeWitt Problem 11.16. You may assume that h_i & h_o do not change for part (B).
(C) Calculate the required length of the heat exchanger if operated in co-current flow, and compare your answer to (A).

4. Water enters a shell and tube heat exchanger at 45,500 kg/h and an inlet temperature of 80 ^oC. The shell and tube exchanger has 2 shell passes and 8 tube passes with a total outer surface area of 925 m^2. The water is heated to 150 ^oC using heated air at 350 ^oC. The air exits the heat exchanger with a temperature of 175 ^oC.
A. Determine the flow rate of air in the heat exchanger, assuming perfect insulation.
B. Determine the overall heat transfer coefficient, U_o, for this process. Use the ε-NTU method and Tables 11.3 and/or 11.4.

5. A shell and tube heat exchanger with 2 tube passes and 1 shell passes is used to heat water (shell-side) with engine oil (tube-side). There are 100 tubes per pass. The tubes are made of copper and have an inside diameter of 0.95 cm and outside diameter of 1.15 cm. The tubes are perfectly clean on the inside, but have a fouling factor on the outside of $R_{f,o}$" = 0.002 m^2-K/W. Water enters the shell at 1.2 kg/s at 31 ^oC and exits at 67 ^oC. Oil enters the tube-side at 112 ^oC and a flow rate of 1.5 kg/s. h_o for the water = 134 W/m^2-K and h_i = 46 W/m^2-K.
A. What is the rate of change of internal energy of the water (in Watts)?
B. What is the outlet temperature of the oil?
C. Determine UA in terms of L, an as-yet undefined length of the tubes.
D. How long must the tubes be per pass to achieve the required heat transfer? Use the LMTD method with the fudge factor, F. (see class handout for graphs needed!)

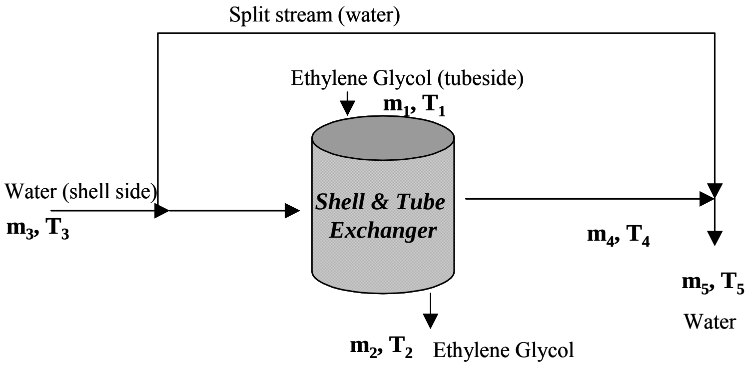
6. Work Incropera and DeWitt 11.38. Use the ε-NTU method.

7. Open heart surgery is normally done in hypothermic conditions, where the patient's blood is cooled before the surgery and re-warmed afterward. A proposed concentric tube counterflow heat exchanger is designed to have a length of 0.5 m and inside tube diameter of 55 mm (thin-walled), and has an overall heat transfer coefficient, U, of 500 W/m^2-K. Given that the blood enters the heat exchanger at 18 ^oC and 0.05 kg/s, and water enters the annulus at 60 ^oC at 0.10 kg/s,
(A) What is the temperature of the blood exiting the exchanger?
(B) How long would the exchanger need to be to achieve a blood outlet temperature of 37 ^oC?
You may assume the mean temperature of the water to be 55 ^oC, and the heat capacity of the blood to be 3500 J/kg-K.

(Continued on Reverse)

8. The shell and tube heat exchanger below is being retrofit to heat a feed stream of ethylene glycol, using supplied plant water that is available in excess.

For the specifications given, determine:
(a) the required mass flow rate of the plant water through the exchanger, $\mathbf{m_4}$.
(b) the number of tubes per pass in the exchanger, $\mathbf{N_T}$.
(c) the temperature of the recombined plant water streams, $\mathbf{T_5}$. *(you may assume c_p is constant so that $m_4(T_5-T_4) = -(m_3-m_4)(T_5-T_3)$).*



<u>ETHYLENE GLYCOL FEED (TUBE)</u>
Inlet Temperature (T_1) = 37 °C
Outlet Temperature (T_2)= 57 °C
Flow Rate = 24 kg/s (m_1)

<u>PLANT WATER (UTILITY-SHELL)</u>
Available supply: 30 kg/s;92 °C (m_3, T_3)
Exchanger Outlet Temp (T_4) = 52 °C

<u>EXCHANGER DESIGN</u>:
Overall Heat Transfer Coefficient (based on outside area) U_o = 732 W/m^2-K
Length = 5 m; Tube side: 2-pass, 1.4 cm outer diameter copper tubes, w/ wall thickness 0.25 cm;
Shell side: 1-pass; baffle spacing of 20 cm

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9. (15 pt BONUS) In the research & development division of your company, a new process using ethylene glycol is being developed, but the ethylene glycol must be chilled before being returned to it's storage tank. Since you don't have time to build a new heat exchanger, you decide to go to Toys Я Us and buy a large kiddie swimming pool that you can fill with water and coil flexible plastic tubing submerged in the water to cool the ethylene glycol from 86 to 28 °C. This is a creative solution--- maybe not the best, but you need to know the length of plastic tubing to get from the warehouse. Given:

1. Ethylene glycol leaves a reaction tank at 3.0 kg/min at 86 °C and must be cooled to 28 °C.
2. A large volume of water will fit into the kiddie pool such that the water can be assumed to remain isothermal at 17 °C throughout the process.
3. All of the ethylene glycol enters a single plastic tube that is made of Tygon (k = 0.12 W/m-K) and has an inner diameter of 0.7 cm and outer diameter of 0.9 cm.
4. You may assume that the tubing has been used before and has inner and outer fouling factors equivalent to being used with refrigerating liquids (Table 11.1).
5. Clearly state any other assumptions you make to solve the problem.
6.

Properties of Water (or see Table A.6)	Properties of Ethylene Glycol
β = expansion coefficient = 227.5 * 10^{-6} K^{-1}	see Table A.5
ν = kinematic viscosity = 9.61 * 10^{-7} m^2/s	
α = thermal diffusivity = 1.45 * 10^{-7} m^2/s	
Pr = Prandtl Number = 6.62	
k = thermal conductivity = 0.606 W/m-K	
V = specific volume = 1.002 * 10^{-3} m^3/kg	

A. Determine the required heat transfer rate in Watts.
B. Determine the convective heat transfer coefficient for the ethylene glycol (you may assume fully developed flow and that the inner walls are at a constant temperature).
C. Determine the convective heat transfer coefficient for the stagnant water. For this calculation only, assume that the temperature of the outer surface of the flexible tubing is 27 °C and does not change with position. You may also assume that the plastic tubing is positioned horizontally in the water.
D. Determine UA in terms of length (your answer will be some # * L)
E. How long should the tubing be?
F. Give five (5) inexpensive suggestions that would reduce the length of tubing required.