<u>Heat Exchangers</u>

Practice problems

1. Water at the rate of 68 kg/min is heated from 35 ^oC to 75 ^oC by oil having C_p=1.9 kJ/kg-K. The fluids are used in a counter-flow concentric tube HX where the oil enters at 110 ^oC and leaves at 75 ^oC. Assume U=320 W/m^2 and C_p of water = 4.18 kJ/kg-K. Calculate heat exchanger area. [Ans: 15.8 m^2]

2. If the HX in Problem 1 is replaced by a shell and tube HX with the water making one shell pass and the oil making two tube passes, calculate HX area. Assume same values as in Problem 1. [Ans: 19.53 m^2]

3. A heat exchanger is used to heat an oil flowing through tubes (C_p=1.9 kJ/kg-K) from 15 ^oC to 85 ^oC. Blowing across the outer surface of the tubes to steam at 5.2 kg/s with inlet and exit temperature of 130 ^oC and 110 ^oC respectively. The overall heat transfer coefficient is 275 W/m^2-K and C_p for steam is 1.86 kJ/kg-K. Calculate surface area of HX. What happens if oil flow rate is reduced by a factor of 2? [Ans: 10.8 m^2]

4. A hot water stream of flow rate 1 kg/s is to be cooled from 90 ^oC to 60 ^oC in a heat exchanger, by contact with a large stream of cold water flowing at 2 kg/s and inlet temperature of 40 ^oC. Calculate HX area needed for this configuration for counter-flow arrangement and for cross-flow arrangement with both fluids mixed. Compare the areas. Assume U = 1000 W/m^2-K. [Ans: A_{CF} =4.69 m^2, A_{XF}=5.30 m^2]

5. A counter-flow HX has heat transfer area A=10 m^2 and overall heat transfer coefficient U=500 W/m^2-K. It is used to cool 1.5 kg/s of hot oil initially at 110 ^oC by 0.5 kg/s stream of cold water with inlet temperature of 15 ^oC. C_p values for oil and water are 2.25 kJ/kg-K and 4.18 kJ/kg-K respectively. Calculate the outlet temperature of the two streams and total heat transfer rate. [Ans: $T_{h,out}$=63^{o}C, $T_{c,out}$=90.5^{o}C, q=158 kW]

6. Water at the rate of 4 kg/s is heated from 40 ^oC to 55 ^oC in a shell and tube heat exchanger. On the shell side, one pass is used with water as the heating fluid $\left(\dot{m}_h = 2\text{ kg/s}\right)$ entering the HX at 95 ^oC. The overall heat transfer coefficient is 1500 W/m^2-K and the average water velocity in the 2-cm diameter tubes is 0.5 m/s. Due to space limitations, the tube length

cannot exceed 3 m. Calculate the number of tube passes, number of tubes per pass and the length of the tubes considering the above constraint. [Ans: 2, 25, 1.55 m]

7. In a tube pass, one-shell pass HX, hot fluid enters at 425 ^oC and leaves at 260 ^oC, while the cold fluid enters at 40 ^oC and leaves at 150 ^oC. Find LMTD for (a) parallel flow, (b) counter flow. Which arrangement will transfer more heat and by what factor? Assume same U and heat transfer area. [Ans: (a) 219.5^oC, (b) 246.5^oC, 1.12]

8. A one-shell, two-tube pass HX has total surface area of 5 m^2 and its overall heat transfer coefficient based on this surface area is 1400 W/m^2-K. If 4500 kg/hr of water enters the shell side at 315 ^oC while 9000 kg/hr of water enters the tube side at 40 ^oC, find the outlet temperature. Assume C_p=4.18 kJ/kg-K for both sides. [Ans: T_{he}=146.5^oC, T_{ce}=124^oC]

9. Water is heated in a building from $20^{o}\mathrm{C}$ at a rate of $70\,\mathrm{kg/min}$ by using hot water from a boiler at $110^{o}\mathrm{C}$ in a single pass counterflow heat exchanger. Find the heat transfer rate if hot water flow rate is 90 kg/min. Also find the exit temperatures of both streams. Assume U=320 W/m^2-K, A = 20m^2. $\left[\mathrm{Ans: 263.4\,kW,\ 68^{o}C, 74^{o}C}\right]$

10. Hot exhaust gases are used in a finned tube cross flow heat exchanger to heat 2.5 kg/s of water $\left[C_p = 4.18\,\mathrm{kJ/kg\cdot K}\right]$ from $35^{o}\mathrm{C}\,\mathrm{to}\,85^{o}\mathrm{C}$. The gases $\left[C_p = 1.09\mathrm{kJ/kg\cdot K}\right]$ enter at $200^{o}\mathrm{C}$ and leave at $93^{o}\mathrm{C}$. Overall heat transfer coefficient is $180\,\mathrm{W/m^2\cdot K}$. Calculate the area of the heat exchanger using $\varepsilon - NTU$ method. $\left[\mathrm{Ans: 37.9\,m^2}\right]$

11. It is desired to heat 230 kg/hr of water $\left(C_p = 4.18\,\mathrm{kJ/kg\cdot K}\right)$ form $35^{o}\mathrm{C}$ to $93^{o}\mathrm{C}$ with oil $\left(C_p = 2.1\mathrm{kJ/kg\cdot K}\right)$ having an initial temperature of $175^{o}\mathrm{C}$. The mass flow of oil is also 230 kg/hr. Two concentric tube heat exchangers are available:

heat exchanger 1 - $U = 570\,\mathrm{W/m^2\cdot K}, A = 0.47\ \mathrm{m^2}$

heat exchanger 2 - $U = 370\,\mathrm{W/m^2\cdot K}, A = 0.94\ \mathrm{m^2}$

Which exchanger should be used? Assume counter flow arrangement.

12. Design a counter-flow heat exchanger to use water for cooling hot engine oil from an industrial power station. The mass flow rate of oil is given as 0.2 kg/sec and its inlet temperature is $90^{\circ}\mathrm{C}$. Water is available at $20^{\circ}\mathrm{C}$ but its temperature rise is restricted to $12.5^{\circ}\mathrm{C}$. The outer tube diameter must be less than $5\,\mathrm{cm}$, and inner tube diameter must be greater than 1.5 cm. Engine oil should be cooled to below $50^{\circ}\mathrm{C}$. The maximum length of heat exchanger can be 200 m. Assume thickness of inner tube to be small. C_p, μ and k for oil and water are $\left[2100\,\mathrm{J/kg\cdot K}, 0.03\,\mathrm{kg/m\cdot s}, 0.015\,\mathrm{W/m\cdot K}\right]$ and $\left[4179\,\mathrm{J/kg\cdot K}, 8.55\times10^{-4}\,\mathrm{kg/m\cdot s}, 0.613\,\mathrm{W/m\cdot K}\right]$ respectively.

13. A finned-tube heat exchanger is used to heat 2.35 m^3/s of air at 1 atm from $15^{\circ}\mathrm{C}$ to $29^{\circ}\mathrm{C}$. Hot water enters the tubes at 82°C and air flows across the tubes producing an average overall heat transfer coefficient of 225 W/m^2-K. The total surface area of the heat exchanger is 9.3 m^2. Calculate the exit temperature and heat transfer rate. Assume $\rho_{air} = 1.22\,\mathrm{kg/m^3}, C_{p,air} = 1006\,\mathrm{J/kg\cdot K}$. $\left[Ans: 19.7^{\circ}\mathrm{C},\ 40.34\,\mathrm{kW}\right]$

14. The specified job of a heat exchanger is to lower the temperature of a 1 kg/s stream of hot water from 80°C to 40°C. The available coolant is a 1 kg/s stream of cold water with an inlet temperature of 20°C. The overall heat transfer coefficient is given as $U = 800\,\mathrm{W/m^2\cdot K}$. Calculate the required heat transfer area A assuming the two streams are in (i) parallel flow, (ii) counter flow.

15. Hot water at 90°C flows inside a 2.5-cm ID tube of steel $\left[k = 15\,\mathrm{W/m\cdot K}\right]$ with 0.8-mm wall thickness at a velocity of 4 m/s. The outer pipe of this concentric tube heat exchanger has ID of 3.75-cm and has an engine oil flow through the annular space at 7 m/s. Calculate the overall heat transfer coefficient of this arrangement assuming a tube length of 6 m. Repeat your calculations assuming fouling factor of 0.001 m^2-K/W and 0.0002 m^2-K/W for oil and water side respectively.

16. A finned tube heat exchanger employs condensing steam at 100°C inside the tubes to heat air from 10°C to 50°C as it flows across the fins. A total heat transfer of 44 kW is to be accomplished and $U = 25\,\mathrm{W/m^2 - K}$. Calculate the heat transfer area of the heat exchanger.