Assignment [2018-19]

ME 307: Heat Transfer Equipment Design

---

1. A heat exchanger is to be designed to cool 10 kg/s an engine oil from 360 K to 300 K with cooling water entering the tube side at 290 K at a rate of 15 kg/s.
   Given, $U_o = 500$ W/m^2°C. Estimate heat transfer area, for:

   (a) parallel flow DPHX

   (b) counter flow DPHX

   (c) one shell pass and two tube pass STHX

   (d) cross-flow, both fluids unmixed CFHX

   (e) cross-flow, one fluid unmixed CFHX

2. A cross-flow recuperator (common heat exchanger for gas turbines) with both fluids unmixed is to be designed under a set of conditions and to be operated under different conditions. The hot exhaust gases flow through the tubes, and the cold intake air flow across these tubes. The wall thickness of the tubes is negligible. The heat exchanger do be designed with mass flow rates $\dot{m}_h = \dot{m}_c = 10$ kg/s, heat transfer coefficients $h_h = h_c = 150$ W/m^{2}K, and three end temperatures $T_{hi} = 425$°C, $T_{ci} = 25$°C, and $T_{co} = 210$°C. We wish to determine:

   (a) the heat transfer area of the heat exchanger, and

   (b) the new outlet temperatures after doubling the flow of (1) the hot fluid, (2) the cold fluid, while maintaining the same inlet temperatures.

3. A heat exchanger (condenser) using steam from the exhaust of a turbine at a pressure of 4.0-in. Hg abs. is to be used to heat 11500 kg/h of water from 15.6°C to 43.3°C. The exchanger is to be sized for one shell pass and four tube passes with 60 parallel tube circuits of 0.995-in.-ID and 1.125-in.-OD brass tubing ($k = 104$ W/mK). For the clean exchanger the average heat transfer coefficients at the steam and water sides are estimated to be 3400 and 1700 W/m^{2}K, respectively. Calculate the tube length required for long-term service.

4. Hot oil is to be cooled by water in a 1-shell-pass and 8-tube-passes heat exchanger. The tubes are thin-walled and are made of copper with an internal diameter of 1.4 cm. The length of each tube pass in the heat exchanger is 5 m, and the overall heat transfer coefficient is 310 W/m^{2}K. Water flows through the tubes at a rate of 0.2 kg/s, and the oil through the shell at a rate of 0.3 kg/s. The water and the oil

enter at temperatures of 20°C and 150°C, respectively. Determine the rate of heat transfer in the heat exchanger and the outlet temperatures of the water and the oil.

5. Water is use to cool ethylene glycol in a 18.3-m long double pipe heat exchanger made of 4-std and 2-std (both type M) copper tubing. The water inlet temperature is 15.6°C and ethylene glycol inlet temperature is 82.2°C.

   The flow rate of ethylene glycol is 9.0 kg/s, while that for water is 14.0 kg/s. Calculate the expected outlet temperature of the ethylene glycol and the pressure drop expected for both streams. Assume counter-flow, and place the ethylene glycol in the inner tube.

   Reverse the direction of either fluid, and repeat the calculation for parallel flow.

   Repeat calculation by placing water in the pipe and ethylene glycol in the annulus.

6. A plate and frame heat exchanger is used to exchange heat in a water-to-water flow system. Hot water enters the exchanger at 32.2°C with a flow rate of 0.0126 m^3/s. Cold water also at 0.0126 m^3/s enters the exchanger at 12.8°C. The exchanger contains 27 plates. The plate spacing is 5.08 mm, the plate material is stainless steel, the plate thickness is 1.016 mm, the plate width is 381 mm, the plate height is 0.914 m. Determine the outlet temperatures of the both the fluids.

7. Water enters a cross-flow heat exchanger at a temperature of 85°C and a flow rate of 2.5 kg/s. Air enters the exchanger at 20°C, leaves at 40°C, and has a flow rate of 12 kg/s. Which type of cross-flow heat exchanger will have the greater effectiveness - mixed-unmixed or unmixed-unmixed? Does it make a difference which fluid is mixed?

8. A bank of four diesel engines is used with alternators for the generation of electricity. The exhaust from the engines is discharged to the atmosphere. It is proposed to use all or part of the exhaust for heating air, which can then be used for space heating to reduce costs. From measurements of velocity, it is determined that the mass flow rate of exhaust available from the engines is 90 kg/hr. The exhaust-gas temperature is 600 K. The air is available at 20°C and is not of much use unless it can be heated to at least 80°C at a mass flow rate of 100 kg/hr. There are a number of 4 x 3 double-pipe exchangers that are 2 m long and made of type K copper tubing with compression fittings. Determine (a) how many of them are required, (b) the overall coefficient of (all) the exchanger(s), and (c) the pressure drop for each stream. Assume that, diesel exhaust has the same properties as carbon dioxide gas.

9. Water at a flow rate of 5,000 kg/h will be heated from 20°C to 35°C by hot water at 140°C. A 15°C hot water temperature drop is allowed. A number of 3.5 m hairpins of 3 in. (ID = 0.0779 m) by 2 in. (ID = 0.0525 m, OD = 0.0603 m) counterflow double-pipe heat exchangers with annuli and pipes, each connected in series, will be used. Hot water flows through the inner tube. Fouling factors are: $Rf_i = 0.000176$ m^2 K/W, $Rf_o = 0.000352$ m^2 K/W. Assume that the pipe is made of carbon steel ($k =$ 54 W/mK). The heat exchanger is insulated against heat losses.

- Calculate the number of hairpins.
- Calculate the pressure drops.

10. Steam at a saturation temperature of 100°C is condensing in a bundle of 320 tubes within a 0.56 m wide duct. The tubes are arranged in a square, in-line pitch (p = 35.0 mm). The bundle is made of up to 20 rows of tubes with 3 cm OD and with 16 tubes in each row. The tube wall temperature in each row is kept constant at 93°C. The steam flows downward in the bundle, and at the 6th row of tubes, the local mass flow rate of vapour is 14.0 kg/s. Find the average heat transfer coefficient.

11. Water is being heated in a STHX by condensing steam. The water is flowing in the tubes at a rate of 0.8 kg/s. The water enters the heat exchanger at 15°C and leaves at 58°C. The steam condenses on the shell side of the heat exchanger at a condensing pressure of 110 kPa. Determine the following:

    (a) Mass flow rate of the condensing steam (kg/s)

    (b) Heat transfer rate between the water and condensing steam (kW)

    (c) UA product of the heat exchanger (kW/K)

    Consider a situation where the cold water inlet temperature to the heat exchanger is adjusted to 20°C while its flow rate (0.8 kg/s) remains constant. For this scenario, determine the following:

    (a) Outlet temperature of the cold water (°C)

    (b) Heat transfer rate between the water and condensing steam (kW)

12. In an industrial facility, air is to be preheated before entering a furnace by geothermal water at 120°C flowing through the tubes of a tube bank located in a duct. Air enters the duct at 20°C and 1 atm with a mean velocity of 4.5 m/s, and flows over the tubes in normal direction. The outer diameter of the tubes is 1.5 cm, and the tubes are arranged in-line with longitudinal and transverse pitches of $S_L = S_T =$ 5 cm. There are 6 rows in the flow direction with 10 tubes in each row. Determine the

rate of heat transfer per unit length of the tubes, and the pressure drop across the tube bank.

13. The evaporator of a refrigeration cycle is a shell and tube design being used to chill water. The water flows in the tubes while the refrigerant boils in the shell. The water enters the heat exchanger at a flow rate of 50 L/s. The average temperature of the water through the heat exchanger is 8°C. The shell of the heat exchanger has a diameter of 21.25 in. The tubes in the heat exchanger have a length of 4 m and are 3/4-in. 16 BWG tubes on a 1 in. square pitch. Determine the pressure drop (kPa) on the tube side of the heat exchanger for a 1-pass, 2-pass, and 4-pass tube design.

14. A STHX has a single shell and 4-tube passes. The shell diameter is 25 in. The shell contains 10 baffles with a spacing of 0.36 m. Water flows through the shell with a flow rate of 70 kg/s and an average temperature of 85°C. The tubes are $1\frac{1}{4}$-in. 13 BWG tubes on a $1\frac{9}{16}$-in. square pitch. Determine the following:

    (a) Shell-side convective heat transfer coefficient (W/m2 K)

    (b) Shell-side pressure drop (kPa)

15. 1.25 kg/s engine oil needs to be heated from 30°C to 50°C using hot water available at 100°C. Design suitable DPHX, and report the following information about the heat exchanger:

    (a) Tube dimensions

    (b) Mass flow rate of water

    (c) Outlet temperature of water

    (d) Pressure drop of each fluid in the heat exchanger

    (e) Motor power required for the pumps assuming 60% pump efficiency.

16. Design a DPHX to be used as a engine oil cooler. 120 kg/s of oil enters the annulus of the heat exchanger at 102°C and leaves at 65°C. The coolant to be used is city water entering the tube side at 21°C with a flow rate of 65 kg/s. Pressure drop is limited to 150 kPa.

17. Design a STHX that will heat water from 30°C to 60°C using engine oil available at 100°C. The flow rate of both fluids is the same, at 12 kg/s. Specify the following information about the heat exchanger:

    (a) Number of shell and tube passes

    (b) Diameter of the shell

(c) Placement of the fluids (which fluid is in the shell? in the tubes?)

(d) Type of tubes used in the shell (BWG specification)

(e) Pitch of the tubes

(f) Number of active tubes

(g) Length of the tubes

(h) Outlet temperatures of the engine oil

(i) Pressure drop of each fluid in the heat exchanger

18. Design a shell-and-tube heat exchanger to be used as a engine oil cooler. 120 kg/s of oil enters the shell side of the heat exchanger at 102°C and leaves at 65°C. The coolant to be used is city water entering the tube side at 21°C with a flow rate of 65 kg/s. Shell-side pressure drop is limited to 150 kPa.

19. Consider the following data to design a water-cooled, shell-and-tube Freon condenser for the given heat duty:

    - Cooling load of the condenser: 125 kW
    - Refrigerant: R-134a
    - Condensing temperature, 37°C
    - In-tube condensation
    - Coolant: City water
    - Inlet temperature: 18°C
    - Outlet temperature: 26°C
    - Mean pressure: 0.4 MPa
    - Heat transfer matrix: 3/4 inch OD 20 BWG
    - Copper tubes

20. One counter-flow heat exchanger functions as a boiler. Water enters with mass flow rate of 0.01 kg/s and temperature 30°C. The water flows through the heat exchanger at constant pressure of 30 bar. The combustion gas used to heat the water enters at 400°C and flows at atmospheric pressure constant pressure with mass flow rate of 0.10 kg/s. The specific heat capacity of the combustion gas is approximately constant and equal to 1000 J/kg-K. Assuming the required pinch temperature = 5 ± 2°C, estimate the steam generation rate and steam exit temperature. Recalculate the values for steam pressures of 1 bar and 10 bar.