Assignment I [2021]

ME 307: Heat Transfer Equipment Design

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1. For heat exchanger operation with equal values of heat capacity rates ($C = C_a = C_b$), show that,

$$T_{a,o} = T_{a,i} - \frac{T_{a,i} - T_{b,i}}{C/UA + 1}$$

   In a counter-flow heat exchanger, cold water enters at 30°C at a rate of 0.5 kg/s, and hot water enters at 65°C at the same flow rate. If UA of the heat exchanger is 4 kW/K, estimate the ΔT_{LM} and the heat exchange rate.

2. For phase-change heat transfer in heat exchanges, show that,

$$T_o = T_i + (T_{sat} - T_i)\,(1 - \exp(-UA/C))$$

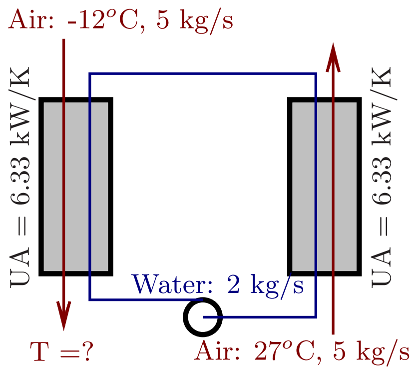
   Water is heated from 25 to 50°C by steam condensing at 110°C. If the water flow rate remains constant, but its inlet temperature drops to 15°C, what will its new outlet temperature be?

3. A flow rate of 2 kg/s of water, $C_p = 4.19$ kJ/kg.K, enters one end of a counterflow heat exchanger at a temperature of 20°C and leaves at 40°C. Oil enters the other side of the heat exchanger at 60°C and leaves at 30°C. If the heat exchanger were made infinitely large while the entering temperatures and flow rates of water and oil remained constant, what would be the rate of heat transfer in the heat exchanger be?

4. A counterflow heat exchanger cools 5 kg/s of oil, $C_p = 2.4$ kJ/kg.K, with water that has a flow rate of 7.5 kg/s. The specific heat of water is 4.19 kJ/kg.K. Under the original operating conditions, the oil is cooled from 75 to 40°C when water enters at 25°C. To what temperature will the oil be cooled if it enters at 65°C and if there is no change in the in entering water temperature, the flow rates of either fluid, or the heat transfer coefficients?

5. A double-pipe heat exchanger serves as an oil cooler with oil flowing in one direction through the inner tube and cooling water in the opposite direction through the annulus. The oil flow rate is 0.63 kg/s, the oil has a specific heat capacity of 1.68 kJ/kg, the water has flow rate 0.5 kg/s, and its specific heat is 4.19 kJ/kg.K. In a test of a prototype, oil entering at 78°C was cooled to 54°C when the entering water temperature was at 30°C. The possibility of increasing the area of the heat exchanger is to be considered . If the flow rates, fluid properties and entering temperatures remain unchanged, what will be the expected outlet temperature of the oil if the area is increased by 20%?

6. To ventilate a factory building, 5 kg/s of factory air at 27°C is exhausted, and an identical flow rate of air at - 12°C is introduced to take its place. To recover some of the heat of the exhaust air, heat exchangers are placed in the exhaust and the ventilation air ducts, and 2 kg/s of water is pumped between the two heat exchangers, The UA value of both of these counterflow heat exchangers is 6.33 kW/K. What is the temperature of air entering the factory?



7. Light lubricating oil ($c_p = 2090$ J/kgK) is cooled by allowing it to exchange energy with water in a small heat exchanger. The oil enters and leaves the heat exchanger at 375 and 350 K, respectively, and flows at a rate of 0.5 kg/s. Water at 280 K is available in sufficient quantity to allow 0.201 kg/s to be used for cooling purposes. The overall heat-transfer coefficient may be taken as 250 W/m^{2}K. Determine the required heat-transfer area for

   (a) counterflow

   (b) parallel-flow

   (c) crossflow, water-mixed

   (d) shell-and-tube with four tube-side passes, oil being the tube-side fluid

8. In the energy exchange between water and lubricating oil as considered in the above example, a crossflow heat exchanger with the shell-side fluid (water) mixed is constructed with a heat-transfer area of 1.53 m^2. A new pump is attached to the water supply line, enabling the water flow rate to be increased to 1000 kg/h. What will be the exit temperatures of the water and oil for the new operating conditions?

9. The condenser of a steam power plant operates at a pressure of 7.38 kPa. Steam at this pressure condenses on the outer surfaces of horizontal tubes through which cooling water circulates. The outer diameter of the pipes is 3 cm, and the outer surfaces of the tubes are maintained at 30°C. Determine

   (a) rate of heat transfer to the cooling water circulating in the tubes

   (b) rate of condensation of steam per unit length of a horizontal tube

   If 12 horizontal tubes arranged in a rectangular array of 3 tubes high and 4 tubes wide, recalculate the values.

10. A heat exchanger is to be designed to cool 9.0 kg/s an engine oil [$c_p = 2100$ J/kg°C] from 90°C to 60°C with cooling water [$c_p = 4200$ J/kg°C] entering the tube side at 30°C at a rate of 4.5 kg/s. Given, $U_o = 500$ W/m^2°C. Estimate heat transfer area,

    (a) for one shell pass and two tube pass heat exchanger.

    (b) for cross-flow heat exchanger where both fluids are unmixed.

    (c) for cross-flow heat exchanger where one fluid is unmixed.

11. In a CFHX, 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 $h_h = h_c = 100$ W/m^2 K, and three end temperatures $T_{hi} = 350$°C, $T_{ci} = 25$°C, and $T_{co} = 150$°C. Estimate:

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

    (b) the new outlet temperatures after doubling the flow of the hot fluid.

12. Oil is to be heated to 45 °C from 30°C using hot water at 100°C. Oil flow rate is 0.03 kg/s in the annulus, while water flow rate is 0.5 kg/s.The heat exchanger is made of 2 x 1 1/4 std type M copper tubing. Use appropriate fouling factors, size the DPHX.

13. In a cross-flow recuperator with both fluids unmixed, hot air flows 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.

14. 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.

15. 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.