ME109 – Heat Transfer

Midterm 2- Fall'04

Instructor: Prof. A. Majumdar

Nov 23, 2004; 5:10 pm - 6:30 pm; Maximum Points = 30

NOTE: This is an open book, open notes exam.

1. To keep the passengers warm in a car, the waste heat from a car exhaust is utilized through a counter flow heat exchanger to heat up the interior air (the one circulated for the passengers). The car exhaust has a volumetric flow rate of 0.5 m^3/s and the inlet temperature at the heat exchanger is 110 ºC. The interior air enters the heat exchanger at 10 ºC and a volumetric flow rate of 0.05 m^3/s. The over all heat transfer coefficient of the heat exchanger is U = 500 W/m^2-K, and the surface area used for the heat exchanger is A = 0.1 m^2. Assume the densities and heat capacities of both streams to be ρ = 1 kg/m^3 and C_p = 1 kJ/kg-K, respectively.
    a. Determine the (i) effectiveness; (ii) total heat transfer rate; (iii) outlet conditions of the interior air. (HINT: Use NTU method. For a counterflow heat exchanger: $\varepsilon = \dfrac{1 - exp\left[-NTU\left(1 - C_r\right)\right]}{1 - C_r\, exp\left[-NTU\left(1 - C_r\right)\right]}$; where $C_r = \left(\dot{m}C_p\right)_{min} / \left(\dot{m}C_p\right)_{max}$ (9)
    b. If you want hotter air coming out of your heating vent in your car, should you reduce the fan speed or increase the fan speed of the interior air? Explain qualitatively using effectiveness-NTU graphs. (1)

2. In an air conditioner, the coolant enters a tube of diameter 0.0075 m at a mean temperature of –10 ºC and a flow rate of 0.015 kg/s. On the outside of the pipe, water vapor condenses and keeps the tube wall at 5 ºC (dew point of the air). Assume the flow to be fully developed. The properties of the coolant can be assumed to be ρ = 1440 kg/m^3, $\nu = 2 \times 10^{-7}$ m^2/s, C_p = 900 J/kg-K, k = 0.07 W/m-K.
    a. What is the heat transfer coefficient inside the tube? [Hint: For laminar flow (Re_D < 2000), Nu_D = 3.66; for turbulent flow (Re_D > 2000); $Nu_D = 0.023 Re_D^{0.8} Pr^{0.4}$](4)
    b. If the pipe is 0.1 m long, what is the coolant temperature at the outlet? (4)
    c. What is the total heat transfer rate, q? (2)

3. A particle of hail (made of ice) can be assumed to be a sphere of diameter D = 0.005 m which travels through the atmosphere at a speed U = 10 m/s. When traveling through regions which are at temperatures higher than the melting point of water (0 ºC), the surface of the hail particle remains at 0 ºC and the energy absorbed is used to melt the ice into water. The average Nusselt number can be estimated from the correlation $Nu_D = 2 + 0.6 Re_D^{1/2} Pr^{1/3}$. The properties of air are: ρ = 1 kg/m^3; C_p = 1 kJ/kg-K, k = 0.026 W/m-K; $\nu = 1.6 \times 10^{-5}$ m^2/s.
    a. What is the heat transfer coefficient for the hail particle? (7)
    b. If the ambient air through which the hail particle travels is at 27 ºC, what is the heat transfer rate to the particle? If the latent heat of melting is 334 kJ/kg, what is the rate of ice melting (in kg/s)? (Assume that the diameter does not change)(3)