ChE 350 Problem Set 10

Due Thursday April 7, 2016

Supplementary Reading: Sections 7.1, 7.3-7.6, 8.5-8.7, 9.6-9.8 in Bergman

1. The wind chill that is experienced on a cold windy day is due to increased heat transfer from exposed human skin to the surrounding air. You are asked to come up with an expression for "wind chill" based on your knowledge of forced and natural convection. Wind chill expresses the equivalent air temperature that would be experienced by the body in natural convection when losing heat at the same rate as it does in forced convection to air at the ambient temperature. The average human body may be approximated as a 1.8 *m* vertical cylinder with an inner core diameter of 30 *cm* surrounded by a skin layer. The human skin can be modeled as a 3 *mm*-thick layer of fatty tissue (k = 0.2 $Wm^{-1}K^{-1}$) whose interior surface is maintained at a controlled temperature of 37°C. Based on these assumptions, establish relationships for predicting the wind chill for ambient temperatures between -15°*C* and 10°*C* and wind speeds between 5 and 40 *mph*.

2. Water at 45°C flows at a rate of 0.34 kgs^{-1} through a Teflon tube (k = 0.2 $Wm^{-1}K^{-1}$) of 20 *mm* outer radius and 3 *mm* wall thickness. The tube is mounted horizontally in quiescent air at a temperature of 15°*C*, and a thin electrical heating tape is wrapped around the outer surface of the tube.

a. Neglecting radiation exchange, calculate the heat flux that must be supplied by the tape to ensure a uniform water temperature of 45°C in the tube.

b. If the emissivity of the tape is 0.95 and the surroundings are also at 15°*C*, recalculate the required heat flux by accounting for radiation exchange.

c. If the heating tape delivers a uniform surface heat flux of 1 kWm^{-2}, what fraction of the power dissipated by the tape is transferred to the water in the tube in the absence of radiation exchange?

d. (Extra credit) Accounting for radiation exchange, what fraction of the power dissipated by the tape is transferred to the water in the tube?

3. It is desired to heat engine oil to a mean temperature of 80°*C* by passing it through a 5-*mm*-diameter tube with a constant wall temperature of 150°*C*. The oil enters the tube at 45°*C* and a mass flow rate of 1 kgs^{-1}. The thermophysical properties of engine oil at different temperatures are given below:

320 *K*: ρ = 872 kgm^{-3} ; c = 1,990 $Jkg^{-1}K^{-1}$; k = 0.141 $Wm^{-1}K^{-1}$; ν = 1.62X10^{-4} m^2s^{-1}

340 *K*: ρ = 860 kgm^{-3} ; c = 2,080 $Jkg^{-1}K^{-1}$; k = 0.139 $Wm^{-1}K^{-1}$; ν = 6.2X10^{-5} m^2s^{-1}

360 *K*: ρ = 848 kgm^{-3} ; c = 2,160 $Jkg^{-1}K^{-1}$; k = 0.137 $Wm^{-1}K^{-1}$; ν = 3.0X10^{-5} m^2s^{-1}

a. Determine the required tube length using physical property values at a mean temperature of 62.5 $^\circ C$.

b. Calculate the actual entrance and exit Reynolds numbers. Is the assumed flow regime in the heat transfer calculations of part (a) correct? Recalculate the required tube length by properly accounting for the nature of flow in the tube.