Heat Transfer

Home Assignments 1B (Heat transfer for flow over flat plates, cylinders and spheres)

1. The top surface of a passenger train, moving at a velocity of 70 kmph, absorbs solar radiation at a rate of 200 W/m^2. The ambient air temperature is 30^oC. Assuming that the 2.8 m wide and 8 m long flat roof is insulated from the bottom, and that the radiative exchange with the surrounding is negligible as compared to convection, determine the mean equilibrium temperature of the roof. [35.1^o C]

2. A Fluid at 25^oC and 1 atm is blowing over a long flat plat with a velocity of 8 m/s. Determine the distance from the leading edge of the plate where the flow becomes turbulent, and thickness of the hydrodynamic and thermal boundary layer thicknesses if the fluid is (a) air, (b) water and (c) liquid sodium.

3. A 10 cm diameter steam pipe with external surface temperature of 110^oC passes through an open area where a cross-wind blows perpendicular to the pipe at 1 atm pressure and a velocity of $U_\infty = 8$ m/s. The free-stream temperature of air is 10^o C. Find the rate of heat loss from the pipe per unit length. [1093 W]

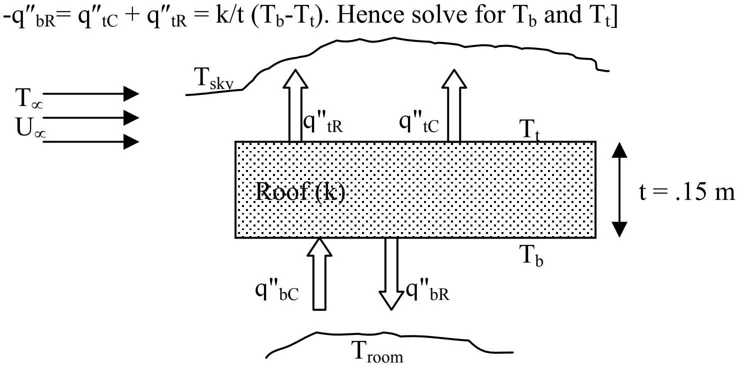
4. A 25 cm diameter stainless steel ball (ρ=8055 kg/m^3, C_p = 480 J/kg.K) is removed from the oven at a uniform temperature of 300^oC. The ball is then subject to the flow of air at 1 atm pressure and 25^o C with a velocity of 3 m/s. The surface temperature of the ball eventually drops to 200^oC. Determine the average convection heat transfer coefficient during this cooling process, and estimate how long the process will take. [13.8 W/m^2K, 86 min]

5. While solving these heat transfer problem your head generates approximately 21 W of heat. If you are sitting next to a fan that blows air at 1 atm pressure, 10^o C and at 35 km/h velocity, determine the average surface temperature of your head. Assume your head to be a sphere of 30 cm diameter. [12.7^oC]

6. The roof of a house consists of a 15 m × 20 m and 15 cm thick flat concrete slab (k= 2 W/mK). The convection heat transfer on the inner surface of the room is 5 W/m^2. On a clear winter night, the ambient air is reported to be at 10^oC, while the night sky temperature is at 100K. Interior of the house and the internal surfaces of the walls are maintained at a constant temperature of 20^oC. The emissivity of both surfaces of the concrete roof is 0.9. Considering both radiation and convection heat transfer, determine the rate of heat transfer through the roof, when the ambient air is blowing at 60 km/h blowing over the roof. [28 kW]

   [Hint: $q''_{bR} = \varepsilon(T_{room}^4 - T_b^4)$, $q''_{bC}=5$, $q''_{tR} = \varepsilon(T_t^4 - T_{sky}^4)$, $q''_{tC} = \bar{h}\,(T_t - T_\infty)$: involves unknown T_b and T_t

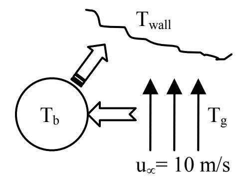
   Two equations: $q''_{bC} - q''_{bR} = q''_{tC} + q''_{tR} = k/t\,(T_b - T_t)$. Hence solve for T_b and T_t]



7. In a particular application involving air flow over a heated surface, the boundary layer temperature distribution may be approximated as $\frac{(T - T_s)}{(T_\infty - T_s)} = 1 - \exp\left(-\Pr\frac{U_\infty y}{\nu}\right)$ where y is the distance normal to the surface and Pr=0.7. If T_∞=400K, T_s = 300K and $U_\infty/\nu = 5000\ m^{-1}$, what is the surface heat flux?

8. In a boiler furnace, the hot flue gas, flowing out of the furnace region at a mean velocity of 10 m/s, temperature is measured by an R-type thermocouple inserted in the furnace space. What is the actual gas temperature if the thermocouple reads 1000 K? The bead of the thermocouple has a diameter of 800 micron, and the bead surface emissivity is 0.9. Consider the furnace walls to be blackbody at 700 K.

   [Hint: The sensing part of a thermocouple is the circular bead that forms due to the bimetallic junction. In the above problem, the bead receives heat from the gas (at T_g) by convection, and exchanges radiative heat with the furnace walls (at T_w). Under steady state, heat gained from gas = heat lost by radiation to the furnace wall. Thus $h(T_g - T_b) = \varepsilon\sigma(T_b^4 - T_w^4)$, or $T_g = T_b + \frac{\varepsilon\sigma}{h}(T_b^4 - T_w^4)$. The temperature reading from thermocouple is the bead temperature (T_b), which is slightly lower than the actual gas temperature (T_g). This "temperature correction" of thermocouple is primarily required at high temperature measurements (e.g., for measuring flame temperature in a furnace). In this problem, T_b, T_w, ε and σ are known, while h is to be calculated considering T_b to be the first approximation for film temperature.]



9. Atmospheric air at 20°C flows with a free stream velocity of 5 m/s over a 2 m diameter spherical tank which is maintained at 80°C. Compute the average heat transfer coefficient and the rate of heat transfer from the air to the air. Neglect radiation. [63.2 W/m^2·K, 29.8 W]

10. Consider the laminar boundary layer flow of a liquid metal with velocity u_∞ and temperature T_∞ over a flat plate maintained at a uniform temperature T_w. Taking the temperature profile of the form $\theta(x,y) = \frac{T(x,y) - T_w}{T_\infty - T_w} = \sin\left(\frac{\pi}{2}\frac{y}{\delta_t}\right)$ develop an expression for the local heat transfer coefficient h_x.

    [Hint: For liquid metal Pr<<1. Use the Integral Energy Eq. to derive the equation fro h_x.]