Indian Institute of Technology, Kharagpur

Mechanical Engineering Department

Heat Transfer (ME 30005) – Autumn Semester 2019
Class Test – 2

Full marks: 25 | **Duration: 60 minutes**

All questions are compulsory

---

1. Air at 2 atm and 200°C is heated as it flows through a tube of inner diameter 2.5 cm (1-in) with a velocity of 10 m/s.
   a. Calculate the heat transfer per unit length of the tube if a constant heat flux condition is maintained at the wall and the wall temperature is 20°C above the air temperature for the entire length of the tube (neglect developing length).
   b. How much would the bulk air temperature increase over a 3-m length of the tube?

   Assume $\rho = 1.5\ kg/m^3$, $Pr = 0.7$, $\mu = 2.6 \times 10^{-5}\ kg/m\text{-}s$, $k = 0.04\ W/m\text{-}K$ and $C_p = 1.025\ kJ/kg\text{-}K$

   5+5 = 10

2. A thin sheet of metal of dimensions *W x L* is rolled to make a tube of diameter *D* and length *L* through which a refrigerant is made to flow. The tube is now placed horizontally (length normal to gravity) in a chamber full of saturated vapour which now condenses on the outer surface of the tube. In a parallel set-up another sheet of identical dimensions is cut into 3 equal pieces and rolled to form three tubes of equal diameter that are stacked vertically on top of each other. Which of these arrangements will result in higher condensation heat transfer and by what percentage?

   5

3. A metal cylinder with black anodized surface and having a diameter of 2.5-cm is placed horizontally and maintained at 37°C in an infinite and quiescent ambient of air at 17°C.
   a. Qualitatively plot the variation of convective heat transfer coefficient along the surface of the cylinder
   b. Calculate the rate of heat transfer from the metal surface under these conditions.

   Assume $\rho = 1.03\ kg/m^3$, $Pr = 0.7$, $\mu = 2.\times 10^{-5}\ kg/m\text{-}s$ and $k = 0.03\ W/m\text{-}K$.

   3+7 = 10

Useful data

Stefan Boltzmann constant: 5.667×10^{-8} W/m²-K⁴

Coefficient of Wien's law: 2900 μ-K

Planck's Law: $e_{b\lambda} = \frac{2\pi C_1}{\lambda^5\left[e^{C_2/\lambda T}-1\right]}$ where $C_1 = 5.96 \times 10^{-17}$ W-m², C_2= 0.014387 m-K

Correlations

$Re = \frac{\rho U D}{\mu}$ $Ra = \frac{g\beta\Delta T L^3}{\alpha\nu}$

Forced Convection:

- Isothermal Flat Plate: $Nu_x = 0.332 Re_x^{1/2} Pr^{1/3}$ (laminar flow); $Nu_x = 0.0296 Re_x^{4/5} Pr^{1/3}$ (turbulent flow)
- Circular pipe – Laminar Flow
  $\overline{Nu_D} = 3.66$ -> Isothermal wall $\overline{Nu_D} = 4.36$ -> Isoflux wall
- Circular pipe – Turbulent Flow
  Dittus-Boelter equation: $\overline{Nu_D} = 0.023 Re_D^{4/5} Pr^n$ *[n=0.3 for heated wall; n=0.4 for cold wall]*

Natural Convection:

- Vertical Flat Plate:
  Laminar Flow ($Ra_L < 10^9$)

$$\overline{Nu_L} = 0.68 + \frac{0.670\, Ra_L^{1/4}}{\left[1+(0.492/\Pr)^{9/16}\right]^{4/9}}$$

  Turbulent Flow ($10^9 < Ra_L < 10^{12}$)

$$\overline{Nu_L} = \left\{0.825 + \frac{0.387\, Ra_L^{1/6}}{\left[1+(0.492/\Pr)^{9/16}\right]^{4/9}}\right\}^2$$

- Horizontal cylinder:

$$\overline{Nu_D} = \left\{0.60 + \frac{0.387\, Ra_D^{1/6}}{\left[1+(0.559/\Pr)^{9/16}\right]^{8/27}}\right\}^2 \qquad Ra_D < 10^{12}$$

- Sphere:

$$\overline{Nu_D} = 2 + \frac{0.589\, Ra_D^{1/4}}{\left[1+(0.469/\Pr)^{9/16}\right]^{4/9}}$$

Laminar film condensation

$$\overline{Nu_L} = 0.943\left[\frac{\rho_l g(\rho_l-\rho_v)h'_{fg}L^3}{\mu_l k_l(T_{sat}-T_w)}\right]^{1/4}$$ → Vertical plate

$$\overline{Nu_D} = C\left[\frac{\rho_l g(\rho_l-\rho_v)h'_{fg}D^3}{\mu_l k_l(T_{sat}-T_w)}\right]^{1/4}$$ → C = 0.826 for sphere; C = 0.729 for horizontal cylinder

$$\bar{h}_{D,N} = 0.729\left[\frac{g\rho_l(\rho_l-\rho_v)k_l^3 h'_{fg}}{N\mu_l(T_{sat}-T_s)D}\right]^{1/4}$$ for vertical stack of N tubes