Indian Institute of Technology, Kharagpur
Mechanical Engineering Department

Heat Transfer (ME 30005) – Autumn Semester 2017
End-Semester Exam

Time: 3 hrs *Attempt all questions. Clearly state the assumptions made.* *Full Marks: 120*

1. A long rod of radius R_o contains uniformly distributed source of volumetric heat generation q'''. The conductivity (k) of the rod depends on temperature and it loses heat by convection from the surface. Write the governing differential equation with appropriate boundary conditions for steady state.

   Consider the above case when the surface temperature (T_w) of the rod is kept constant. For R_o = 1 cm, T_w = 350 °C, $k = \frac{3167}{T+273}$ (k is in W/m-K and T is in °C) find out the rate of volumetric heat generation which will produce a centerline temperature of 2000 °C. Sketch the temperature profile.

   10+10 = 20

2. In a sauce pan of 1 litre of water initially at 20°C is to be boiled under atmospheric pressure over an electric heater of 3 kW power. The diameter of the heater and the sauce pan is 0.3 m. Consider 30% heat is lost to the atmosphere. The heat transfer co-efficient in boiling near atmospheric pressure is given by the correlation

   $h = 1.95(q''_w)^{0.72}(P)^{0.24}$ where h is in W/m^2-K, q''_w is in W/m^2 and P is in bar

   a. How long does it take the water to start boiling?
   b. What is the temperature of the bottom surface of the sauce pan during boiling?
   c. Estimate the time required for complete vapourisation of water.
   d. Compare the applied heat flux with critical heat flux.

   Use the following properties: ρ_l = 958.1 kg/m^3; C_{pl} = 4.216 kJ/kg-K; ρ_v = 0.5974 kg/m^3; σ = 58.92 x 10^{-3} N/m; h_{fg} = 2257.3 kJ/kg; T_{sat} = 100 °C at 1.013 bar

   20

3. a) The inlet and outlet temperature of the fluid streams in a double pipe heat exchanger is given below:

Stream	Inlet temp., °C	Outlet temp., °C
Hot	220	100
Cold	80	120

   Identify the flow arrangement. Determine the LMTD and effectiveness of the heat exchanger. If you have to estimate the overall heat transfer co-efficient for the heat exchanger, what minimum information would you require? Clearly explain your answer.

   b) A pure vapour is being condensed in a parallel flow heat exchanger. The pressure decreases continuously from the inlet to the outlet in the vapor stream. Sketch the variation of temperature of the two streams along the length of the heat exchanger. Will the performance of the heat exchanger change if the streams are arranged in counter flow?

   14+6 = 20

4. a) The configuration of a furnace can be approximated as a duct with cross-section of an equilateral triangle. The duct is sufficiently long so that end effects are negligible. The hot wall having emissivity of 0.75 is maintained at 1000K, while the cold wall with an emissivity of 0.7 is maintained at 350K. The third wall is a re-radiating surface. Determine the radiation heat flux leaving the hot wall.

b) The wall of a hot furnace has a small opening of 2-cm diameter for viewing. The inside temperature of the furnace is 1273K while the outer wall of the furnace and all surrounding surfaces are maintained at 300K. Assuming all surfaces to be black, calculate the heat loss by radiation from the small opening. Explain the rationale behind your calculation.

12 + 8 = 20

5. Air at 1 atm and 75C enters a tube of internal diameter 4-mm with an average velocity of 2 m/s. The tube length is 1-m and with a constant heat flux boundary condition over the entire length. If the exit bulk mean temperature of the air is 125°C, calculate (a) heat transfer coefficient at the exit plane, (b) the constant surface heat flux and (c) the wall temperature at the exit plane.
Use the following properties of air at average bulk mean temperature of 100°C: $\rho = 0.95$ kg/m^3; $C_p = 1.01$ kJ/kg-K; $\mu = 2.18 \times 10^{-5}$ kg/m-s; $k = 0.03$ W/m-K; Pr = 0.7

If the heated length is now restricted to the last 2-cm of the tube while keeping the fluid temperatures at the inlet and exit to be the same, what will be the modified wall temperature at the exit plane

10 + 10 = 20

6. Answer the following short questions:

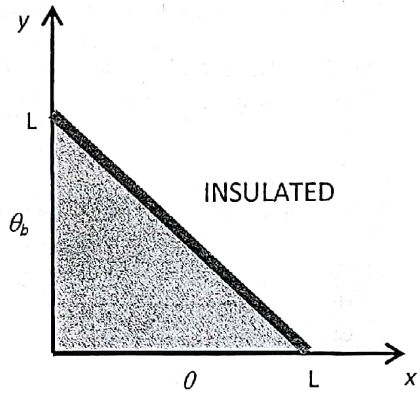
5 x 4 = 20

a) The Nusselt number for fully developed internal flow through a tube with uniform temperature boundary condition is 3.6. This implies that the average heat transfer coefficient is insensitive to the velocity or flow rate of the fluid. However, our intuition suggests that the heat transfer rate should increase with increase in fluid flow rate. Explain this anomaly.

b) During a walk in the park on a winter evening, we often find swarms of mosquitoes just above our head. They follow us as we move and gather again above our heads. What may be the possible reason?

c) For condensation over a bank of N vertical in-line cylinders, the correlation shows that the average heat transfer coefficient at $N^{-1/4}$. Explain physically why the h_{avg} should reduce with N.

d) Using the examples of 2-D conduction discussed in class, how will you solve the temperature field for the prism with the cross-section of a right angled triangle. State the governing equation and boundary conditions only (do NOT solve).



Useful data

Stefan Boltzmann constant: 5.667×10^{-8} W/m^2-K^4

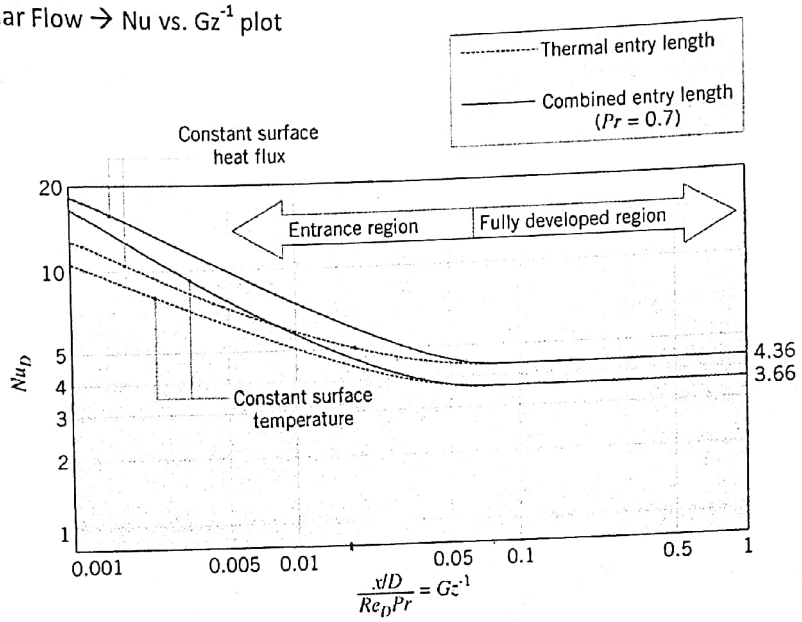
Coefficient of Wien's law: 2900 μ-K

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

Correlations

Forced Convection:

Circular Pipe – Laminar Flow → Nu vs. Gz^{-1} plot



Circular pipe – Turbulent Flow (Dittus Boelter Correlation for $Re_D > 10{,}000$)

$$\overline{Nu_D} = 0.023 Re_L{}^{4/5} Pr^n$$

[n=0.3 for heated wall; n=0.4 for cold wall]

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

Pool Boiling Correlations

Nucleate Boiling – Rohsenow's Correlation

$$q_s'' = \mu_l h_{fg}\left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2}\left(\frac{c_{p,l}(T_w-T_s)}{C_{s,f}h_{fg}\,\mathrm{Pr}_l^n}\right)^3$$

n = 1.0 for water
= 1.7 for other liquids

Critical heat flux for a finite horizontal surface facing up:

$$q''_{\max} = 0.149 h_{fg}\rho_v\left[\frac{\sigma g(\rho_l-\rho_v)}{\rho_v^2}\right]^{1/4}$$

Film Boiling:

$$\overline{Nu_D} = \frac{h_{conv}D}{k_v} = C\left[\frac{g\rho_v(\rho_l-\rho_v)h'_{fg}D^3}{\mu_v k_v(T_w-T_s)}\right]^{1/4}$$