Roll No ....

MMTP - 103

M.E./M.Tech., I Semester

Examination, June 2016

Heat And Mass Transfer

Time : Three Hours

Maximum Marks : 7(

Note : i) Answer any five questions.
ii) Any missing data may be assumed suitably.

1. a) i) Derive the general heat conduction equation ir cylindrical co-ordinates as given below.

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\frac{\partial T}{\partial r}\right]+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}+\frac{q_0}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Where q_0 is the rate of heat generation per uni volume inside the solid.

ii) Show that the maximum temperature in a cylindrica rod with heat generation $q_0\left(kW/m^3\right)$ is given by:

$$\frac{T_{\max}}{T_\infty}=1+\frac{q_0}{4h_c}\frac{R}{T_\infty}\left[2T\frac{h_c R}{k}\right]$$

Where h_c is the convective heat transfer coefficier and T_∞, the ambient temperature.

b) Determine the maximum current in a 1mm diameter bare aluminium (k = 204 W/mk) wire can carry without exceeding a temperature of 200°C. The wire is suspended in air at temperature 25°C and h = 10W/m^2k. The electrical resistance of this wire per unit length is 0.037 ohm/m.

2. a) i) By using the separation of variables method, solve the Laplacian for a two-dimensional heat conduction problem. Why are the isotherms and adiabatics orthogonal?

ii) What is lumped system analysis for transient heat conduction? When is it applicable?

b) A thermocouple junction may be considered as a sphere. It is to be used to measure the temperature of a gas stream. The following particulars are known:

k of the thermocouple junction = 20 W/mk,

C = 400 J/kg-k, ρ (Density) = 8500 kg/m^3

If the heat transfer coefficient is 400 W/m^2-k, estimate the (A) junction diameter needed for the thermocouple to have the thermal time constant of 1sec, and (B) time required for the junction to reach 198°C, if the junction is initially at 25°C and is placed in the gas stream which is at 200°C.

3. a) i) Explain how do the average values of Nusselt number for natural convection depend on whether

I) hot surface is facing up or down,

II) plate surface is warmer or cooler than the surrounding fluid, and

III) plate is subjected to uniform wall heat flux or uniform wall temperature.

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ii) Show that the axial distribution of mean temperature T_b for a fluid flowing inside a pipe whose surface is maintained at constant temperature T_s is given by

$$\frac{T_s - T_{b,o}}{T_s - T_{b,i}} = e^{-\bar{h}\, PL/mCp}$$

Where P = perimeter, L=length,

m = mass flow rate of fluid and Cp = specific heat.

b) An oil at 20°C flows at an average velocity of 2m/s through a pipe line 30cm in diameter. A 200 m long section of the pipe line passes through icy water of a lake at 0°C. The measurements reveal that the surface temperature of the pipe is very near to 0°C. Neglecting the thermal resistance of the pipe material, determine

i) Temperature of oil when it leaves the lake and

ii) The pumping power required to overcome the pressure losses due to friction.

Take properties at 20°C as

ρ(density) = 888 kg/m³, Cp = 1880J/kg-k

k = 0.145 W/m-k, μ = 0.8 kg/m-s,

μ_s = 3.85 kg/m-s

Thermal entry length for laminar flow $L_e = 0.05\,\mathrm{Re}_D.\mathrm{Pr}.D$

and in this zone $Nu_D = 1.86(\mathrm{Re}_D.\mathrm{Pr}.D/L)^{1/3}(\mu/\mu_s)^{0.14}$

and friction factor $f = \dfrac{64}{\mathrm{Re}_D}$

4. a) i) Sketch the velocity and temperature profiles for a heated vertical plate suspended in still air. If forced convection heat transfer is dominating, then what should be the value of $\left(Gr/\mathrm{Re}^2\right)$?

ii) A thin horizontal plate of length 100cm and width 10cm is maintained at 130°C in a large tank full of water at 70°C. Estimate the rate of heat input required to maintain the temperature of 130°C. Take properties of water at 100°C as

$\rho = 960 kg/m^3$, $\beta = 0.75 \times 10^{-3}$, $Cp = 4216$ J/kg-k

k = 0.68W/m–k, ν (viscosity) = 0.294×10^{-5}m²/s.

Recommended correlations for horizontal plates are:

Upper surface heated or lower surface cooled

$$Nu_L = 0.54 Ra_L^{1/4} \qquad \left(2.6\times10^4 < Ra_L < 10^7\right)$$

and $$Nu_L = 0.15 Ra_L^{1/3} \qquad \left(10^7 < Ra_L < 3\times10^{10}\right)$$

Lower surface heated or upper surface cooled

$$Nu_L = 0.27 Ra_L^{1/4} \qquad \left(3\times10^5 < Ra_L < 3\times10^{10}\right)$$

b) The configuration of a furnace can be approximated as an equilateral triangular duct which is sufficiently long that the end effects are negligible. The hot wall is maintained at T_1 = 1000k and has an emissivity $\varepsilon_1 = 0.8$. The cold wall is at T_2 = 500k and has an emissivity $\varepsilon_2 = 0.8$. The third wall is reradiating zone for which $Q_3 = 0$. Calculate the net radiation flux leaving the hot wall.

5. a) i) Show that the emissive power of a black body is π-times the intensity of radiation

ii) On what factors does the radiant heat exchange between two bodies depend? What is shape factor? Show that

$$A_1F_{12} = \frac{1}{\pi}\int_{A_1}\int_{A_2}\frac{\cos\phi_1\cos\phi_2}{r^2}dA_1\,dA_2 = A_2F_{21}$$

b) A small sphere of OD 60mm, with a surface temperature of 300°C, is located at the geometric centre of a large sphere of ID 360mm with an inner surface temperature of 15°C. Calculate how much of heat emitted from the large sphere inner surface is incident upon the outer surface of the small sphere, assuming that both surfaces approach black body behaviour. What is the net exchange of heat between the two spheres?

6. a) i) What is nucleate boiling? Why do bubbles always form on the heating surface? What are nucleation sites? When does a bubble grow or collapse as it moves up through the liquid?

ii) State the assumptions made in deriving Nusselt's equation for film condensation. How does the Nusselt's equation for condensation on a horizontal tube differ from that on a vertical tube?

b) A square array of 400 tubes (horizontal), 15mm outer diameter, is used to condensate steam at atmospheric pressure. The tube walls are maintained at 88°C by a coolant flowing through the tubes. Calculate the amount of steam condensed per hour per unit length of the tube.

Given: The properties of condensate at mean film temperature of 94°C.

$\rho_f = 963 kg/m^3$, $\mu_f = 3.06 \times 10^{-4} kg/m-s$,

$k = 0.678 W/m-k$, $h_{fg} = 2255 \times 10^3 J/kg$

7. a) Define the convective mass transfer coefficient. Define Schmidt, Sherwood and Lewis numbers. What is the physical significance of each? Discuss the analogy between heat and mass transfer.

b) The temperature of an air stream is to be measured, but the thermometer available does not have a sufficiently high range. Accordingly, a damp cover is wrapped around the thermometer before it is placed in the air stream.

The thermometer reading is 22°C. Estimate the true air temperature assuming it is dry at atmospheric pressure.

If the air stream is at 50°C while the wet bulb temperature is still 22°C estimate the relative humidity of the air stream.

At 22°C

$$P_{AS} = 2617\, N/m^2,\ h_{fg} = 2449\, kJ/kg$$

$$D_{AB} = 0.26 \times 10^{-4}\, m^2/s$$

$$C_p = 1.008\, kJ/kg - k$$

$$\alpha = 26.2 \times 10^{-6}\, m^2/s$$

The properties of air at 36°C are:

$$\rho = 1.14\, kg/m^3$$

$$C_p = 1.006\, kJ/kg - k$$

$$\mu = 2 \times 10^{-6}\, N.s/m^2$$

At 50°C saturation concentration = 0.0817 kg/m^3

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8. Write short notes on any five of the following:

i) Mass function and mass lines

ii) Conduction shape factor and its use

iii) Critical Thickness of insulation on a small diameter pipe

iv) Distinguish between

a) A black body and grey body

b) Absorptivity and emissivity of a surface

v) Modified graph of number and thermal contact resistance

vi) Filmwise and Dropwise condensation

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