HEAT TRANSFER
(MECH 3102)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) The radiation shape factor of a surface with respect to itself is
(a) always zero
(b) zero for a concave surface
(c) zero for a convex surface
(d) more than zero for a flat surface.

(ii) For forced convection heat transfer, the Nusselt number is a function of
(a) Prandtl number and Biot number
(b) Reynolds number and Grashoff number
(c) Prandtl number and Grashoff number
(d) Reynolds number and Prandtl number.

(iii) Which of the following describes thermal diffusivity?
(a) $\rho^2 kc$ (b) $\frac{1}{\rho kc}$ (c) $\frac{k}{\rho c}$ (d) $\frac{\rho c}{k}$
[symbols have usual meaning]

(iv) In a heat exchanger, the cold fluid enters at 30^{0}C and leaves at 110^{0}C. The hot fluid enters at 180^{0}C and leaves at 160^{0}C. The capacity ratio of the heat exchanger is
(a) 0.25 (b) 0.33 (c) 0.2 (d) 1.5.

(v) The Grashof number can be represented as
(a) $\frac{Inertia\ force}{Buoyancy\ force}$ (b) $\frac{Buoyancy\ force}{Inertia\ force}$
(c) $\frac{(Viscous\ force)(Buoyancy\ force)}{(Inertia\ force)^2}$ (d) $\frac{(Inertia\ force)(Buoyancy\ force)}{(Viscous\ force)^2}$

(vi) The Stanton number is represented as
(a) $\frac{Nu}{Re^{0.5}Pr}$ (b) $\frac{Nu}{Re^{0.5}Pr^{0.33}}$ (c) $\frac{Nu}{RePr}$ (d) $\frac{Nu}{Re^{0.25}Pr^{0.33}}$

(vii) Choose the wrong statement out of the following:
(a) An equation which represents a physical phenomenon must be dimensionally homogeneous
(b) The nominal thickness of thermal boundary layer represents the distance from the surface to the point where velocity is 99 percent of free-stream value
(c) The Reynolds Colburn analogy correlates fluid friction and heat transfer in laminar flow
(d) The mean film temperature is the arithmetic mean of the solid surface temperature and the free-stream temperature.

(viii) Thermal radiation consists of electromagnetic waves of wavelength between
(a) 0.1 – 100 μm (b) 1.0 – 100 μm
(c) 0.76 – 100 μm (d) 0.1 – 1000 μm.

(ix) Identify the wrong statement
(a) a blackbody emits more radiation than any real body at a given temperature
(b) a blackbody absorbs all radiations incident upon it
(c) solar radiations contain entire band of thermal radiation
(d) a blackbody emits radiation uniformly along all directions.

(x) A heat exchanger with heat transfer surface area A and overall heat transfer coefficient U handles two fluids of heat capacities C_{max} and C_{min}. The parameter NTU is specified as
(a) AUC_{min} (b) U/AC_{min} (c) UA/C_{min} (d) UA/C_{max}.

Group – B

2. (a) A wall of constant thermal conductivity and of thickness 120 cm has left- and right hand surface temperatures of 0°C and 40°C respectively. Determine the temperature of the central plane. How much material has to be added to the left side if the above plane temperature has to be raised by 5°C? How much material is to be removed from the right side to achieve the same? Assume the end surface temperatures remain unaltered after addition or removal of material.

(b) In a cylindrical fuel element for a gas cooled reactor, the generation rate of thermal energy within the fuel element due to fission can be approximated by the relation $q(r) = q_0\left[1-\left(\frac{r}{a}\right)^2\right] W/m^3$ where a is the radius of the fuel element and q_0 is a constant. The boundary surface at $r = a$ is maintained at a uniform temperature T_0. Assuming one-dimensional, steady-state heat flow calculate the temperature drop from centreline to the surface of the fuel element for the following data.

$$q_0 = 3 \times 10^7 \, W/m^3 \, , a = 30 \, mm, k \; = \; 15 \; W/m^0C$$

6 + 6 = 12

3. (a) Consider a tube with inner and outer radii r_i and r_o for one dimensional heat transfer along radial direction. The temperatures at inner and outer surfaces are maintained at T_i and T_0 respectively ($T_0 > T_i$). The thermal conductivity of the material of the tube is temperature dependent and can be expressed as $k = k_0 (1 + a T)$ where k_0 and a are constants. Obtain an expression for the heat transfer per unit length of the tube. (Assume no heat generation).

(b) A hollow sphere of inner radius 30 mm and outer radius 50 mm is electrically heated uniformly at the inner surface at a rate of 10^5 W/m^2. At the outer surface, it dissipates heat by convection into a fluid at 100^{0}C with a heat transfer coefficient of 400 W/m^2-K. Determine the temperatures at inner and outer surfaces. It may be assumed that there is no heat generation within the shell and the thermal conductivity of the material is 15 W/m-K.

6 + 6 = 12

Group – C

4. (a) Two very long rods of same diameter, one made of brass ($k = 85 \, W/m^0C$) and the other of copper ($k = 375 \, W/m^0C$), have one of their ends inserted into a furnace. At a section 10.5 cm away from the furnace, the temperature of the brass rod is 120°C. At what distance from the furnace end, the same temperature would be reached in the copper rod? Both the rods are exposed to the same environment.

(b) A long cylindrical wood log $\left(\rho = 550 \;\; kg/m^3 \, ; \, c_p = 0.24 \, J/kg \quad ; \, k = 0.17 \, W/m°\mathrm{C}\right)$ is $100 \, mm$ in diameter and is initially at uniform temperature of 10°C. It is exposed to hot gases at 700°C in a fireplace with a heat transfer coefficient of $h = 40 \, W/m^2°\mathrm{C}$. If the ignition temperature of wood is 420°C, how long will it be before the log ignites?

6 + 6 = 12

5. (a) A cylindrical stainless steel (k = 25 W/m-K) ingot, 10 cm in diameter and 25 cm long, passes through a heat treatment furnace which is 5 m in length. The initial ingot temperature is 90°C, the furnace gas is at 1260°C and the heat transfer coefficient h is 100 W/m^2-K. Calculate

the maximum speed with which the ingot can move the furnace if it must attain 830°C temperature.

(b) The sun is a nearly spherical radiation source with an approximate diameter of 1.385×10^9 m and is located at a distance of 1.5×10^{11} m from the earth's surface. On a clear day the energy flux associated with solar radiation on the surface of the earth has been accurately calculated as 1135 W/m^2 with an additional 285 W/m^2 absorbed by the earth's atmosphere. Assuming that the the sun emits as blackbody, calculate its surface temperature.

6 + 6 = 12

Group – D

6. (a) The velocity distribution in a laminar boundary layer for flow over a flat plate is given by $\frac{u}{U_\infty} = \frac{y}{\delta}$ where $u(y) = u$ and $u(y = \delta) = U_\infty$. Calculate (i) the ratio of displacement thickness to boundary layer thickness and (ii) the ratio of momentum thickness to boundary layer thickness.

(b) Air is flowing over a smooth flat plate with a velocity of $12 \, m/s$. The velocity profile is in the form $\frac{u}{U_\infty} = \left[2\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2\right]$. The length of the plate is 1.1 m and width 0.9 m. Find (i) the maximum distance from the leading edge upto which laminar boundary layer exists, and (ii) maximum thickness of the laminar boundary layer. Take the kinematic viscosity of air as $\nu = 0.15 \times 10^{-4} \, m^2/s$.

(c) Air at atmospheric pressure and 200°C flows over a plate with a velocity of $5 \, m/s$. The plate is $15 \, mm$ wide and is maintained at a temperature of 120°C. Calculate (i) the thickness of the thermal boundary layer and (ii) the local heat transfer coefficient at a distance of 0.5 m from the leading edge. Assume that flow is on one side of the plate. Take the following properties of air:

$$\rho = 0.815 \;\; kg/m^3 \, , k = 0.0364 \;\; W/m°\mathrm{C} \, ; \, \mu = 24.5 \times 10^{-6} \, Ns/m^2 \;\; ; Pr = 0.7$$

(2 + 2) + (2 + 2) + (2 + 2) = 12

7. (a) Air at a temperature of 30°C flows over a flat plate with a speed of 1.8 m/s. The flat surface has a sharp leading edge and its total length equals 750 mm. Calculate (i) the average drag coefficient (ii) the average shear stress and (iii) the ratio of the average shear stress to the shear stress at the trailing edge. Properties of air at the film temperature:

$$\rho = 1.165 \;\; kg/m^3 \, ; \; \mu = 18.68 \times 10^{-6} \, Ns/m^2 \, ; \; \nu = 16 \times 10^{-6} \, m^2/s$$

(b) Air at a temperature of 30°C and at 1 bar pressure flows over a flat plate at a speed of 2.2 m/s. The plate surface temperature is 90°C. The length and the width of the plate is 900 mm and 450 mm respectively. Calculate the heat transfer rate from (i) first half of the plate (ii) next half of the plate. Take the following properties of air at the mean bulk temperature 60°C:

$\rho = 1.06\ kg/m^3$; $\nu = 18.97 \times 10^{-6}\, m^2/s$; $Pr = 0.696$; $k = 0.02894\ W/m°C$

(c) Air flows over a heated flat plate at a speed of 50 m/s. The local skin coefficient at a point on the plate is 0.004. Using the Reynolds-Colburn analogy, estimate the local heat transfer coefficient at this point. Take the following properties of air:

$\rho = 0.88\ kg/m^3$; $\mu = 2.286 \times 10^{-5}\, Ns/m^2$; $c_p = 4.178\ kJ/kg°C$; $k = 0.035\ W/m°C$

(2 + 1 + 2) + (2 + 2) + 3 = 12

Group – E

8. (a) When 0.5 kg of water per minute is passed through a tube of 20 mm diameter, it is found to be heated from 20°C to 50°C. The heating is accomplished by condensing steam on the surface of the tube and subsequently the surface temperature of the tube is maintained at 85°C. Determine the length of the tube required for fully developed flow. Take the thermophysical properties of water at 60°C as:

$\rho = 983.2\ kg/m^3$; $k = 0.659\ W/m°C$; $\nu = 0.478 \times 10^{-6}\, m^2/s$; $c_p = 4.178\ kJ/kg°C$

(b) A cylindrical body 350 mm diameter and 2 m height is maintained at a constant temperature of 50°C. The surrounding temperature is 15°C. Find the amount of heat generated by the body per hour. At the mean film temperature, the thermo-physical properties of air are:

$\rho = 1.026\ kg/m^3$; $k = 0.0247\ W/m°C$; $c_p = 0.96\ kJ/kg°C$; $\nu = 15.06 \times 10^{-6}\, m^2/s$; $\beta = \frac{1}{298}\, °C^{-1}$.

Use the relation $Nu = 0.12(Gr.Pr)^{0.33}$ as the correlation for convection coefficient.

6 + 6 = 12

9. (a) Show by the method of dimensional analysis that for *natural* convection heat transfer the Nusselt number is a function of the Grashoff number and the Prandtl number.

(b) In a counter-flow double pipe heat exchanger, water is heated from 25°C to 65°C by oil with a specific heat of 1.45 $kJ/kg°C$ and mass

flow rate of 0.9 kg/s. The oil is cooled from 230°C to 160°C. If the overall heat transfer coefficient is 410 $W/m^2°C$ calculate (i) the rate of heat transfer (ii) the mass flow rate of water (iii) the surface area of the heat exchanger.

5 + (2 + 2 + 3) = 12