B.TECH/ME/5TH SEM/MECH 3102/2016

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) Identify the wrong statement for a gray-opaque surface
(a) $\rho = 1- \varepsilon$ (b) $\varepsilon = \alpha$ (c) $\tau = 0$ (d) $\rho = \varepsilon = 1$.

(ii) For validity of lumped capacitance method, the following must be satisfied:
(a) Bi = 1 (b) Bi < 1
(c) Bi < 0.1 (d) Bi <0.01, where Bi means Biot number.

(iii) Major contribution of contact resistance is due to
(a) gap (b) spot
(c) spot and gap both (d) none of these.

(iv) The correct order with increasing values of thermal conductivity for the materials is
(a) aluminium, gold, silver, copper
(b) aluminium, gold, copper, silver
(c) gold, aluminium, silver, copper
(d) gold, aluminium, copper, silver.

(v) In lumped capacitance method the time constant τ_t is defined as the time required by which the temperature difference with respect to the maximum difference of the solid with the surrounding becomes
(a) 63.2% (b) 36.8%
(c) 50 % (d) 72.3%.

(vi) The ratio of kinematic viscosity to thermal diffusivity is the
(a) Nusselt number (b) Reynolds number
(c) Prandtl number (d) none of these.

(vii) The Nusselt number in case of forced convection is a function of
(a) Grashoff number and Prandtl number
(b) Reynolds number and Prandtl number
(c) Stanton number and Prandtl number
(d) none of these.

(viii) In convective heat transfer, the Nusselt number
(a) represents the ratio of viscous to inertia force
(b) signifies the non-dimensional velocity gradient at the surface
(c) is the ratio of momentum diffusivity to thermal diffusivity
(d) is the ratio of conduction to convection resistance.

(ix) In a two-fluid heat exchanger, the inlet and outlet temperatures of the hot fluid are 65°C and 40°C respectively. For the cold fluid, these are 65°C and 42°C. The heat exchanger is a
(a) parallel-flow heat exchanger
(b) counter-flow heat exchanger
(c) device with possibilities of both parallel and counter-flow
(d) none of the above.

(x) The degree of approach, in heat exchangers, is defined as the difference between temperatures of
(a) hot medium outlet and cold water outlet
(b) hot medium outlet and cold water inlet
(c) cold water outlet and inlet
(d) hot medium inlet and outlet.

Group – B

2. (a) Derive the steady state heat diffusion equation with constant volumetric heat generation and constant thermal conductivity in Cartesian co-ordinates.

(b) A 1 m long steel tube (k = 15 W/m-K) with an outer diameter of 760 mm and of thickness 130 mm is covered with an insulating material (k = 0.2 W/m-K) of 20 mm thickness. A hot gas with a heat transfer coefficient 400 W/m^2-K flows inside the tube and the outer surface of insulation is exposed to cooler air with a heat transfer coefficient 60 W/m^2-K. Calculate the total thermal resistance of the system for heat transfer from the hot gas to cooler air.

6 + 6 = 12

3. (a) The left and right side of a 20 mm thick plate with constant heat generation of 80 MW/m^3 are found to be at 160^{0}C and 120^{0}C at

steady state. The plate has a constant thermal conductivity of 200 W/m-K. Determine (i) the temperature distribution in the plate along the thickness (ii) the location and the value of maximum temperature (iii) the rates of heat transfer at both ends.

(b) A hollow aluminium sphere of inner and outer radii 150 mm and 200 mm respectively (k = 200 W/m-K) with an electrical heater in the centre is coated with insulating material of thickness 120 mm for an experiment. The inner surface of the sphere is maintained at 300^0 C and the system is in a room at an ambient temperature of 20^0 C with a convective heat transfer coefficient of 25 W/m-K. If a power of 80 W is dissipated at steady state, what is the thermal conductivity of the insulating material?

(2 + 2 + 2) + 6 = 12

Group – C

4. (a) Derive the governing equation for temperature distribution in a fin with constant cross section. Hence find the total heat transfer from an infinitely long fin. Use standard parameters.

(b) A long cylindrical iron bar (ρ = 7800 kg/m³, c_p = 460 J/kg-K, k = 60 W/m-K) of diameter 5 cm, initially at temperature 700^0 C is exposed to a cool air stream at T = 100^0 C with the convective heat transfer coefficient of the environment of 80 W/m²-K. Check the suitability of the 'Lumped Capacitance, method for transience analysis. Find the time required for the temperature of the bar to reach 300^0 C.

(3 + 3) + (2 + 4) = 12

5. (a) Define view factor. Prove reciprocity relationship. Obtain a general expression of view factor.

(b) Two black surfaces A and B, (each a rectangle 1.5 m by 3 m) are parallel and directly opposed to each other. They are 3 m apart. If surface A is at 127^0C and surface B is at 327^0C. Given, the view factor of each surface with respect to the other is 0.11, σ = 5.67 × 10 -8 W/m²-K⁴. Determine (i) the net rate of heat transfer from A to B (ii) the net rate of energy loss from surface A (side facing B only) if the surrounding other than the two surfaces behaves as blackbody at 27^0C.

(2 + 2 + 2) + (2 + 4) = 12

Group – D

6. (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) The velocity distribution in a laminar boundary layer is given by $\frac{u}{U} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^2$, where u is the velocity at a distance y from the plate and u = U at y = δ. Find the thickness of the boundary layer at the end of the plate 1.5 m long and 1 m wide when placed in water flowing with a velocity of 0.12 m/s. Also calculate the value of the drag coefficient. Take μ for water = 0.001 Ns/m².

5 + (5 + 2) = 12

7. (a) Air at 30°C flows with a velocity of 2.8 m/s over a plate of area 1000 mm×600 mm and thickness 25 mm. The top surface of the plate is maintained at 90°C. If the thermal conductivity of the plate material is 25 W/m-K, calculate:
(i) Heat transfer rate from the plate;
(ii) Bottom temperature of the plate for the steady state condition.
Take the following properties of air at mean film temperature 60°C:
$\rho = 1.06\ kg/m^3$; $c_p = 1.005\ kJ/kgK$; $k = 0.02894\ W/mK$;
$\nu = 18.97 \times 10^{-6}\ m^2/s$; $Pr = 0.696$.

(b) Derive the momentum equation for the hydrodynamic boundary layer over a flat plate.

6 + 6 = 12

Group – E

8. (a) Derive a relation between the Grashoff and the Reynolds numbers assuming the heat transfer coefficients over vertical plates for pure forced and free convection are equal in laminar flow.

(b) Two horizontal steam pipes having diameters $100\ mm$ and $300\ mm$ are so laid in a boiler house that mutual heat transfer can be neglected. The surface temperature of each of the steam pipes is 475°C. If the temperature of the ambient air is 35°C, calculate the ratio of heat transfer coefficients and heat losses per meter length of the pipes. Assume only free convection.

(c) The flow rates of hot and cold water streams running through a parallel-flow heat exchanger are $0.2\ kg/s$ and $0.5\ kg/$ respectively. The inlet temperatures on the hot and cold sides are 75°C and 20°C respectively. The exit temperature of hot water is 45°C. If the individual heat transfer coefficients on both sides are 650 W/m^2K, calculate the area of the heat exchanger.

3 + 5 + 4 = 12

9. (a) A vertical cylinder 1.5 m high and 180 mm in diameter is maintained at 100°C in an environment of 20°C. Calculate the heat loss rate by free convection from the surface of the cylinder.

Take the following properties of air at mean film temperature 60°C:

$$\rho = 1.06\ kg/m^3;\ c_p = 1.004\ kJ/kgK;\ k = 0.02894\ W/mK;\ \nu = 18.97 \times 10^{-6}\, m^2/s.$$

Use the following correlations:

$$Laminar\ flow: \overline{Nu_L} = 0.59(Gr.Pr)^{0.25} \quad (10^4 < Gr.Pr < 10^9)$$

$$Turbulent\ flow: \overline{Nu_L} = 0.10(Gr.Pr)^{0.33} \quad (10^9 < Gr.Pr < 10^{12})$$

(b) A cylindrical body of 300 mm diameter and 1.6 m height is to be maintained at a constant temperature of 36°C. The surrounding temperature is 14°C. Find the amount of heat generation rate by the body.

Take the following properties of air at mean film temperature 25°C:

$$\rho = 1.025\ kg/\ \ ^3;\ c_p = 0.96\ kJ/kgK;\ k = 0.0247\ W/mK;$$

$$\beta = \frac{1}{298}K^{-1};\ \nu = 15.06 \times 10^{-6}\, m^2/s.$$

Assume the relation $\overline{Nu_L} = 0.12(Gr.Pr)^{0.33}$.

6 + 6 = 12