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) All the following are the units of thermal conductivity except
(a) kcal/m-hr-°C (b) kJ/m-hr-K (c) W/m-s-K (d) cal/cm-s-°C.

(ii) A composite wall of furnace has two layers of equal thickness having thermal conductivity in the ratio of 3 : 2. The ratio of temperature drop across the two layers for a steady conduction is
(a) 2 : 3 (b) 3 : 2 (c) 1: 2 (d) ln 2: ln 3.

(iii) The heat flow equation through a hollow spherical shell of radii r_1 and r_2 ($r_2 > r_1$) is to be written in the same form For wall thickness (r_2 - r_1), the equivalent mean radius for the spherical shell is
(a) $(r_2 + r_1)/2$ (b) $(r_2 - r_1)/2$ (c) $(r_2 \times r_1)^{1/2}$ (c) $(r_2 - r_1)/\ln (r_2/r_1)$.

(iv) The temperature drop in a plane wall with uniform heat generation can be decreased by
(a) reducing wall thickness
(b) decreasing heat generation
(c) increasing thermal conductivity of wall material
(d) all of these.

(v) For enhancement of heat transfer from a hot surface, fins are provided
(a) to increase the temperature gradient
(b) to increase in turbulence
(c) to increase the surface area
(d) to decrease the pressure drop.

(vi) In the lumped parameter model, temperature variation is
(a) linear (b) cubic (c) exponential (d) logarithmic.

(vii) Transient heat transfer means
(a) very little heat transfer
(b) heat transfer for a short time
(c) heat transfer with small temperature gradient
(d) unsteady conduction

(viii) With an increase in wave-length, the monochromatic emissive power of a black body
(a) increases (b) increases, reaches a maximum and then decreases
(c) decreases (b) decreases, reaches a minimum and then increases.

(ix) The temperature gradient in the fluid flowing over a heated plate in normal direction will be
(a) zero at the plate surface
(b) positive at the surface
(c) very steep at the top of thermal boundary layer
(d) zero at the top of thermal boundary layer.

(x) The dimensionless parameter $\frac{l^3\rho^2}{\mu^2}\beta g\Delta T$ is referred to as
(a) Stanton number (b) Schmidt number
(c) Grashof number (d) Peclet number.

Group – B

2. (a) The temperature of a surface is maintained at 300°C by separating it from an air flow by a layer of insulation 20 mm thick for which the thermal conductivity is 0.01 W/m-K. If the air temperature is 30°C and the convective heat transfer coefficient between the air and the outer surface of insulation is 400 W/m^2-K, determine the temperature of this outer surface.

(b) The thermal conductivity of pure aluminium is 214.6 W/m-K and 228 W/m-K at 300°C and 200°C, respectively. One surface of a large slab of pure aluminium of thickness 40 cm is exposed to 300°C while the surface is maintained at 200°C. Assuming that the thermal conductivity varies linearly between this temperature, determine the conduction heat flux through the slab.

6 + 6 = 12

3. (a) In an oil fired furnace, the combustion products are at 1000°C and the atmospheric air is at 25°C. The convective heat transfer coefficient between hot combustion products and the furnace wall is 10 W/m^2-K. The same between the outer surface of furnace wall and air is 5 W/m^2-K. The furnace wall is made with fireclay brick whose thermal conductivity is 1.04 W/m-K. Determine the maximum permissible thickness of the furnace wall so that the wall temperature does not exceed 800°C.

(b) In a steam radiator, steam at 110°C is passed through a tungsten steel (k = 54 W/m-K) tube of ID = 2 cm and OD = 3 cm. The surrounding air is at 5°C. The convective heat transfer coefficients at the inner and outer surfaces of the tube are 5000 W/m^2-K and 5 W/m^2-K, respectively. Calculate the rate of heat transfer per meter length of the tube. What are the temperatures at the inner and outer surface of the tube?

6 + 6 = 12

Group – C

4. (a) A carbon steel [k = 54 W/m-K, ρ = 7833 kg/m^3, c_p = 0.465 kJ/kg-K] ball of 10 cm diameter with an initial and uniform temperature of 625°C is suddenly immersed in a large quantity of oil at 25°C. If the convective heat transfer coefficient between the steel ball and oil is 10 W/m^2-K, what is the time required for the ball to reach a temperature of 100°C?

(b) Two parallel black plates 1 m × 2 m are kept 1 m apart. One plate is maintained at 800°C, while the other at 200°C. What is the net rate of heat exchange between them? Given, that the shape factor is 0.29.
Suppose a sphere of radius 1 m is enclosed by another irregular surface of area 20 m^2. If the outer spherical surface and the enclosing inner surface are designated by 1 and 2, write the complete shape factor matrix.

6 + (3 + 3) = 12

5. (a) An aluminium [k = 204 W/m-K] rod of 2 cm diameter and 30 cm long protrudes from a wall which is maintained at 300°C. The end of the rod is insulated and lateral surface of the rod is exposed to air at 30°C. The convective heat transfer coefficient between the rod's surface and air is 10 W/m^2-K. Calculate the rate of heat loss from the rod and the temperature at the mid-point of the rod.

(b) What are the characteristics of black body radiation? Make a comparison between a black body and a gray body. Define radiosity and irradiation.

6 + (2 + 2 + 2) = 12

Group – D

6. (a) Show how the local Nusselt Number can be expressed as equal to the dimensionless temperature gradient.

(b) Consider a flat plate of length l is at a constant temperature T_s. Air with a free stream temperature T_∞ (T_∞ < T_s) flows over the plate. The temperature distribution in air is given by:

$$\frac{T - T_S}{T_\infty - T_S} = \frac{3}{2}\left[\frac{y}{A\sqrt{x}}\right] - \frac{1}{2}\left[\frac{y}{A\sqrt{x}}\right]^3$$

Where x- and y- are the co-ordinates axes along and perpendicular to the plate. The co-ordinate x is measured from the leading edge of the plate, while y co-ordinate is measured from the plate surface. Here A is a constant with dimension $m^{1/2}$. Show that

(i) $Nu_x = \frac{3}{2}\frac{\sqrt{x}}{A}$ (ii) $\overline{Nu_L} = 2Nu_L$

6 + 6 = 12

7. (a) Engine oil at 60°C flows with a velocity of 1 m/s over a 5 m long flat plate whose temperature is 30°C. The flow of air is parallel to the length of the plate. Determine the rate of heat transfer per unit width of the entire plate. The properties of the engine oil at the mean film temperature of 45°C are:
ρ = 870 kg/m^3; Pr = 2850; k = 0.145 W/m-K ; ν = 250 × 10^{-6} m^2/s
Use the correlation $\overline{Nu_L} = 0.664 \times Re^{1/2} \times Pr^{1/3}$ for laminar flow

(b) The local heat transfer coefficient for flow over a flat plate at constant temperature is found to be of the form $h_x = Ax^{-0.25}$ where A *(W/m$^{1.75}$-K)* is a coefficient and x *(m)* is the distance from the leading edge of the plate. Compute the ratio $\overline{h_L}/h_L$. Discuss the significance of Prandtl number (Pr).

6 + (4 + 2) = 12

Group – E

8. (a) A horizontal heated plate at 200°C and facing upwards has been placed in still air at 20°C. If the plate measures 1.25 m × 1 m, make calculations for the heat loss by natural convection.
The convective film coefficient for free convection is given by the following empirical relation:

$$h = 0.32\,(\theta)^{0.25}\,\frac{W}{m^2K}$$

Where θ is the mean film temperature and is the average between the air and the plate.

(b) What is the general empirical relationship for free convection for a variety of circumstances expressed as?
Hot oil [c_p = 2.09 kJ/kg-K] flows through a counter-flow heat exchanger at the rate of 0.7 kg/s. It enters at 200°C and leaves at 70°C. Cold fluid [c_p = 1.67 kJ/kg-K] exits at 150°C at the rate of 1.2 kg/s. Using LMTD method, determine the surface area of the heat exchanger required for the purpose if overall heat transfer coefficient is 650 W/m^2-K.

(4 + 2) + 6 =12

9. (a) Explain clearly with sketches what are velocity boundary layer and thermal boundary layer. Explain clearly the difference between forced convection and free convection.

(b) Water enters a counter-flow double pipe heat exchanger at 35°C flowing at the rate of 0.8 kg/s. It is heated by oil c_p = 1.88 kJ/kg-K] flowing at the rate of 1.5 kg/s from an inlet temperature of 120°C. For an area of 15 m^2, and an overall heat transfer coefficient of 350 W/m^2-K, determine the total heat transfer rate using NTU method. Take c_p of water as 4.18 kJ/kg-K.

(2 + 2 + 2) + 6 = 12

Department & Section	Submission link:
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