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) When does the general heat conduction equation which gives the temperature distribution and conduction heat flow in an isotropic solid reduce to Laplace equation?
(a) If the body or element is in unsteady-state with heat generation
(b) If the body or element is in steady-state with heat generation
(c) If the body or element is in unsteady-state with no heat generation
(d) If the body or element is in steady-state with no heat generation.

(ii) For a long solid cylinder of radius R with uniform volumetric heat generation, the temperature distribution in the dimensionless form is given by $\frac{T-T_w}{T_{max}-T_w}$ = [symbols have usual meaning]
(a) $1-\frac{r}{R}$ (b) $1-(\frac{r}{R})^2$ (c) $1-(\frac{r}{R})^3$ (d) $1-(\frac{r}{R})^4$.

(iii) Water enters a pipe at 20°C at a rate of 0.50 kg/s and is heated to 60°C. The rate of heat transfer to water is approximately
(a) 20 kW (b) 42 kW (c) 84 kW (d) 126 kW.

(iv) A composite wall of a furnace has two layers of same thickness having thermal conductivities in the ratio of 2:3. What is the ratio of temperature drop across the two layers?
(a) 1:2 (b) 2:3 (c) 3:1 (d) 3:2.

(v) Grashoff number is given by
(a) $gD^3.\beta.\Delta t\rho^2/\mu^2$ (b) $gD^2\beta\Delta t\rho/\mu^2$
(c) $gD^2\beta\Delta tP^2\mu$ (d) $gD^3\beta\Delta tP^2/\mu$;
(Symbols have their usual meaning)

(vi) The product of Reynolds number and Prandtl number is known as
(a) Stanton number (b) Biot number
(c) Peclet number (d) Grashoff number.

(vii) The temperature of a solid surface changes from 27°C to 627°C. The emissive power change would then conform to the ratio
(a) 3 (b) 9 (c) 81 (d) 23.2.

(viii) Thermal diffusivity of a substance is
(a) directly proportional to the thermal conductivity
(b) inversely proportional to density of substance
(c) inversely proportional to specific heat
(d) all of the above.

(ix) In free convection heat transfer, Nusselt number is function of
(a) Grashoff number and Reynolds number
(b) Grashoff number and Prandtl number
(c) Prandtl number and Reynolds number
(d) Grashoff number, Prandtl number and Reynolds number.

(x) LMTD in case of counter flow heat exchanger as compared to parallel flow heat exchanger is
(a) higher (b) lower
(c) the same ame (d) depends on the area of heat exchanger.

Group – B

2. (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 the hot combustion products and the furnace wall is 10 W/m^2K. The convective heat transfer coefficient between the atmospheric air and the other side of the furnace wall is 5 W/m^2K. The furnace wall is made of fireclay brick [$k = 1.04\ W/(m.K)$]. Determine the maximum thickness of the wall if the wall temperature is not to exceed 800°C. [(CO2)(Analyze/IOCQ)]

(b) A flat nickel-steel [$k = 19\ W/(m.K)$] plate of 6 cm thickness is used as a heater which produces the effect of uniform heat generation @ 100 W/m^3 by the passage of electric current through it. If the plate is immersed in a flowing fluid at 25°C and the film coefficient under these conditions is 50 W/m^2K, determine the temperatures at either surface of the plate and at the centre. [(CO2)(Understand/IOCQ)]

6 + 6 = 12

3. (a) Inside and outside surfaces of a hollow sphere $a \leq r \leq b$ at $r = a$ and $r = b$ are maintained at temperatures of T_1 and T_2, respectively. The thermal conductivity of the material varies with temperature and given as$k(T) = k_0(1 + \alpha T + \beta T^2)$. Determine the equivalent constant thermal conductivity for the same heat loss under identical configuration of shape and temperatures. [(CO2)(Remember/LOCQ)]

(b) An electric wire of 10 m length and 1 mm diameter dissipates 200 W in air at 25°C. The convective heat transfer coefficient between the wire surface and air is 15 W/m^2K. It is proposed that the wire be covered with electrical insulation of mica [$k = 0.5815\ W/(m.K)$] such that its outer diameter increase to 3 mm. Determine (i) the temperature of the wire before insulation (ii) whether covering with mica will cause heat transfer augmentation effect or insulation effect (iii) interface temperature after mica covering. [(CO2)(Evaluate/HOCQ)]

5 + 7 = 12

Group - C

4. (a) The average heat transfer coefficient for flow of 100°C air over a flat plate is measured by observing the temperature time history of a 3 mm thick copper slab exposed to this air flow. In one test run, the initial temperature of the plate was 210°C and in 5 minutes the temperature decreased by 40°C. Calculate the value of heat transfer coefficient.
[$\rho = 9000\ kg/m^3$; $c = 0.38\ kJ/(kg.K)$; $k = 370\ W/(m.K)$; symbols have their usual meaning] [(CO3)(Analyze/IOCQ)]

(b) In an experiment for the determination of the thermal conductivity of a long solid 2.5 cm diameter rod, its base is placed on the outer wall of a furnace with a large portion of it projecting out in an ambient of 22°C. After the steady state conditions prevail, temperatures at two different points 10 cm apart are measured and found to be 110°C and 85°C. The convective heat transfer coefficient between the ambient and rod surface is determined otherwise, and found to be $28\ W/m^2K$. Determine the thermal conductivity of the rod material. [(CO3)(Evaluate/IOCQ)]

6 + 6 = 12

5. (a) Radiant energy with an intensity of 800 W/m^2 strikes a flat plate in such a way that the direction of propagation makes an angle of 30° with the normal to the plate. The absorptivity is twice the transmissivity and thrice the reflectivity. Determine the rate of absorption, transmission and reflection.
What is Kirchhoff's identity? [(CO3)(Remember/LOCQ)]

(b) A large spherical surface of diameter 20 m has been painted black (emissivity ϵ = 1) and heated by an arrangement located inside. The surface is losing heat to the atmosphere by radiation and natural convection. The convective heat transfer coefficient is $10\ W/m^2K$ and the ambient temperature is 27°C. If the heat produced by the arrangement inside is 1112 kW, what is the steady temperature of the surface? [(CO3)(Analyze/IOCQ)]

6 + 6 = 12

Group – D

6. (a) Engine oil at 75°C flows with a velocity of 1 m/s over a 5 m long flat plate whose temperature is 15°C. The flow 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 a film temperature of 45°C are as follows:
ρ = 870 kg/m^3; Pr = 2850;
k = 0.145 W/(m° C); ν = 250 x 10^{-6} m^2/s. [(CO4)(Analyze/IOCQ)]

(b) Define Nusselt number (Nu) and Prandtl number (Pr). [(CO4)(Remember/LOCQ)]

8 + 4 = 12

7. (a) When 0.6 kg of water per minute is passed through a tube of 2 cm diameter, it is found to be heated from 20°C to 60°C. The heating is achieved by condensing steam on the surface of the tube and subsequently the surface temperature of the tube is maintained at 90° C. Determine the length of the tube required for fully developed flow.
Properties of water at 40° C:
ρ = 995 kg/m^3

$\nu = 0.657 \times 10^{-6}$ m²/s
Pr = 4.340
k = 0.628W/mK
C_p = 4178J/kgK [(CO4)(Analyze/IOCQ)]

(b) Explain the Reynolds Colburn analogy for laminar flow over a flat plate. [(CO4)(Understand/LOCQ)]

8 + 4 = 12

Group - E

8. (a) Consider a 0.6 m × 0.6 m thin square plate in a room at 20°C. One side of the plate is maintained at a temperature of 100°C, while the other side is insulated. Determine the rate of heat transfer from the plate by natural convection if the plate is vertical. The properties of air at the film temperature of 60°C and 1 atm are:
k = 0.02808 W/m°C, Pr = 0.7202
$\nu = 1.896 \times 10^{-5}$ m²/s, $\beta = \frac{1}{T_f} = \frac{1}{333K}$
Use Eq. $Nu = 0.59Ra_L^{1/4}$, if the flow is laminar or Eq. $Nu = 0.1Ra_L^{1/3}$, if the flow is turbulent. [(CO5)(Apply/IOCQ)]

(b) Discuss the various regimes of nucleate boiling. [(CO6)(Understand/LOCQ)]

8 + 4 = 12

9. (a) In a food processing plant, a brine solution is heated from 10°C to 16°C in a double-pipe heat exchanger by water entering at 57°C and leaving at 42°C at the rate of 0.18 kg/s. If the overall heat transfer coefficient is 800 W/(m²K), determine the area of heat exchanger required (i) for a parallel flow arrangement, and (ii) for a counterflow arrangement. Take C_p for water = 4.18 kJ/(kg K). [(CO6)(Analyze/IOCQ)]

(b) Derive equation of Logarithmic Mean Temperature Difference (LMTD) for parallel flow Heat-exchanger. [(CO6)(Understand/LOCQ)]

8 + 4 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	28.12	64.58	7.3

Course Outcome (CO):

After completion of the course, the students will be able to:

CO2	Judge heat transfer rates involving one-dimensional steady-state heat conduction in simple geometries
CO3	Examine heat transfer rates for extended bodies and heat transfer in transient conduction. Explain and appraise radiation heat transfer between black surfaces, as well as between gray bodies.
CO4	Explain concepts related to convection phenomena, examine practical situations where convection heat transfer is dominant, use correlations to describe forced convection phenomena for external and internal flows, and investigate practical problems by applying the knowledge.
CO5	Analyze heat transfer for (i) free convection and (ii) laminar film condensation on a vertical flat plate, and investigate practical situations where such phenomena are predominant.
CO6	Describe boiling heat transfer phenomenon, analyze heat exchanger performance by using the methods of LMTD and ε-NTU, and assemble all relevant concepts to design heat exchanger applications.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question.