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 variation of temperature in a plane wall is determined to be $T(x) = 52x + 25$ $where\ x\ is\ in\ m\ and\ T\ is\ in\ °C$. If the temperature at one surface is 38°C, the thickness of the wall is [(CO2) (Apply/IOCQ)]

(a) 0.10 m (b) 0.20 m (a) 0.25 m (a) 0.40 m.

(ii) The conduction equation boundary condition for an adiabatic surface with direction $\vec{n}$ being the normal to the surface is given by [(CO1) (Understand/LOCQ)]

(a) $T = 0$ (b) $\frac{dT}{dn} = 0$ (c) $\frac{d^2T}{dn^2} = 0$ (d) $-k\frac{dT}{dn} = 1$

(iii) Heat conduction equation through a medium is given in its simplest form as [(CO2) (Understand/LOCQ)]

$$\frac{1}{r}\frac{d}{dr}\left(rk\frac{dT}{dr}\right) + q_G = 0$$

Select the wrong statement below.

(a) The medium is of cylindrical shape
(b) The thermal conductivity of the medium is constant
(c) Heat transfer through the medium is steady
(d) There is heat generation within the medium.

(iv) The value of shape factor of a surface with respect to itself is zero except for the following surface [(CO3) (Apply/IOCQ)]

(a) flat surface (b) outer spherical surface
(c) convex surface (d) concave surface.

(v) Heat is lost at a rate of 275 W per m^2 area of a 15 cm thick wall with thermal conductivity of k = 1.1 W/m-K. The temperature drop across the wall is [(CO2) (Analyze/IOCQ)]

(a) 37.5°C (b) 27.5°C (c) 16°C (d) 8°C.

(vi) Which *one* of the following numbers represents the ratio of kinematic viscosity to thermal diffusivity? [(CO4) (Understand/LOCQ)]
(a) Grashoff number (b) Prandtl number
(c) Mach number (d) Nusselt number.

(vii) The velocity profile of the laminar boundary layer for external flow over a flat plate satisfies the following condition: [(CO4)/(Understand/LOCQ)]
(a) $u = 0$ at $y = 0$ (b) $u = u_\infty$ at $y = \delta$
(c) $\frac{\partial u}{\partial y} = 0$ at $y = \delta$ (d) all of these.

(viii) For hydrodynamically fully developed steady, laminar flow inside a tube, the velocity distribution is [(CO5)/ (Understand/LOCQ)]
(a) linear (b) parabolic
(c) cubic (d) depends on the inlet conditions.

(ix) Boundary layer region is where the [(CO5)/(Understand/LOCQ)]
(a) Velocity gradients are significant
(b) Temperature gradients are significant for non-isothermal flows
(c) Viscous stresses are significant
(d) All of the above.

(x) Choose the *wrong* statement out of the following: [(CO6)/ (Understand/LOCQ)]
(a) Parallel flow or counter flow depends on the relative direction of fluid motion
(b) Logarithmic mean temperature difference is a dimensional quantity
(c) Fouling factor is zero for a new heat exchanger
(d) Heat exchanger effectiveness is the ratio of the maximum possible to actual heat transfer rate.

Group – B

2. (a) An infinite plane wall of thickness $\boldsymbol{l}$ is made of a material whose thermal conductivity $\boldsymbol{k = k_0 T^2}$ [where $\boldsymbol{T}$ is the temperature at any point and $\boldsymbol{k_0}$ is a constant]. Steady 1-D heat transfer occurs through this plane wall with its surfaces maintained at T_1 and T_2. Calculate the heat flux passing through the wall. Also find the mean thermal conductivity of the material which can be substituted in Fourier's law so as to obtain the same heat transfer.
[(CO2) (Analyze/IOCQ)]

(b) Consider an insulated pipe exposed to the atmosphere. Will the critical radius of insulation be greater on calm days or windy days?
In the case of insulation of an electric wire, should the outer radius of insulation be more or less than the critical radius and why?
Explain what is meant by contact resistance. [(CO2) (understand/LOCQ)]

6 + 6 = 12

3. (a) It is required to make a simple standardisation of heat transfer from a standing person. For this purpose the person is idealized to be a vertical cylinder with top and the bottom surfaces fully insulated. The height and diameter of this cylinder

are 1.8 m and 0.3 m, respectively. The lateral surface is at an average temperature of 30°C. For a convective heat transfer coefficient of 15 W/m^2-K, determine the rate of heat loss from this person by convection in an environment at 20°C. [(CO1) (Remember/LOCQ)]

(b) A composite window panel is constructed and installed in a room. The panel has two glass layers of thickness 4 mm each with an in-between layer of air of thickness 10 mm. The thermal conductivity of glass and air are 0.78 W/m-K, and 0.026 W/m-K, respectively. The Panel has a height of 0.8 m with a width of 1.5 m. For a day when the room is maintained at 20°C while the temperature of the outdoors is - 10°C, what is the temperature of the inner surface of the panel under steady state? What is the rate of steady heat transfer? The convective heat transfer coefficients on the inner and the outer surfaces of the window panel are known to be 10 W/m^2-K, and 40 W/m^2-K, respectively. (Radiation effects are included in the coefficients). [(CO2) (Evaluate/HOCQ)]

4 + 8 = 12

Group – C

4. (a) The density and specific heat of a metal are 8500 kg/m^3 and 400 J/kg-K, respectively. A small metal bead (radius 0.5 mm) is made of this metal and kept in a stream of fluid at 20°C. The bead was initially at 100°C and it attains a temperature of 28°C in 4.35 seconds. Consider the bead as a lumped system and find the value of convective heat transfer coefficient between the metal bead and the fluid stream. [(CO3) (Analyze/IOCQ)]

(b) To consider the infinitely long fin model, it is required that the temperature difference with ambient at the tip should be ≤ 0.1% of that at the base. A fin of 10 mm square section protrudes out from a furnace wall maintained at 200°C, and is exposed to air at 30°C with convective heat transfer coefficient of 20 W/m^2-K. The thermal conductivity of the material of the fin is 50 W/m-K. What minimum length is required for the fin to be classified as infinitely long? With this length and so classified, what is the total heat dissipated from the fin? What percentage of the total heat lost is convected till the midpoint?
[(CO3) (Evaluate/HOCQ)]

5 + 7 = 12

5. (a) Two black parallel plates 0.5 m × 1 m each are directly opposed to each other and placed 0.5 m apart. One plate is at 1200 K while the other is at 600 K. They are placed in a room the walls of which are maintained at 300 K and behave as blackbody. The plates exchange heat with each other and also with the walls. Find the net heat exchange by each of the three participants. Given, the shape factor of one plate with respect to the other is 0.29. [(CO3) (Analyze/IOCQ)]

(b) The monochromatic intensity of the radiation emitted by the sun is observed to be maximum at a wavelength of 0.5 μm. Assuming, the sun to be a blackbody, estimate its surface temperature and total emissive power.
A metallic bar at 37°C is placed in a large oven whose interior is maintained at 1100 K. The absorptivity of the bar is 0.8. What is the net rate of

emission/absorption from/to the bar per unit area of its surface? [Take $\sigma = 5.67\times10^{-8}$ W·m^{-2}·K^{-4}] [(CO2) (Apply/IOCQ)]

6 + 6 = 12

Group – D

6. (a) Define local and average heat transfer coefficients. How is local heat transfer coefficient related to temperature gradient at the solid surface? [(CO4)/(Explain/LOCQ]

(b) In convection, what is the mode of heat transfer at the solid surface? The local heat transfer coefficient for flow over a flat plate at constant temperature is found to be of the form $h = Ax^{-0.25}$ (A is a coefficient and x is the distance from the leading edge of the plate).

Show that $\bar{h}_L = 1.33\, h_L$ where $\bar{h}_L$ and h_L are the average heat transfer coefficient over a length L and the local heat transfer coefficient at $x = L$ respectively. [(CO4) (Examine/IOCQ)]

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

7. (a) A flat plate of length L is at a constant temperature T_S. Air with a free stream temperature of $T_\infty (T_\infty < T_S)$ flows over the plate. The temperature distribution in air is given by

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

Here ‘x’ and ‘y’ are the coordinate axes along and perpendicular to the plate. The coordinate x is measured from the leading edge of the plate, while y is measured from the plate surface (A is a constant and depends upon the properties of air and the nature of velocity distribution in the hydrodynamic boundary layer). Show that:

$Nu_x = \frac{1}{2}\frac{\sqrt{x}}{A}$

$\overline{Nu_L} = 2\, Nu_L$ [(CO4) (Analyze/IOCQ)]

(b) Air at pressure of 1 atm and temperature 30°C enters a tube of 25 mm diameter with a velocity of 10 ms^{-1}. The tube is heated in a way that a constant-heat-flux of 2 kW/m^2 is maintained at the wall whose temperature is 20°C above the bulk mean air temperature throughout the length of the tube. Determine the (i) exit bulk mean temperature of air and (ii) and the overall Nusselt number. The length of the tube is 2m. Neglect axial conduction. Take for air: $\rho = 1.2\ kg/m^3$; $c_p = 1000\ J/kgK$. [(CO4) (Analyze/IOCQ)]

5 + 7 = 12

Group – E

8. (a) Engine oil at 70°C flows with a velocity of $2\, m/s$ over a 4 m long flat plate. The plate surface temperature is 20°C. Determine the rate of heat transfer per unit width of the plate.

The properties of engine oil at mean film temperature are given as:

$\nu = 2.4 \times 10^{-4}\, m^2/s$; $\rho = 870\, kg/m^3$; $k = 0.14\, W/mK$; $Pr = 2.8 \times 10^3$
For laminar flow over a flat plate, use the relation:
$Nu_x = 0.332 Re_x^{0.5} Pr^{0.33}$ [(CO4) (Solve/IOCQ)]

(b) Estimate the heat loss from a vertical wall exposed to nitrogen gas at $1\, atm$ pressure and 4°C. The wall is $2.0\, m$ high and $2.5\, m$ wide, and is maintained at uniform temperature 56°C. The average Nusselt number over the height of the plate for natural convection is given by $\overline{Nu}_H = 0.13(GrPr)^{0.33}$.
The properties for nitrogen at the mean film temperature are given as:
$k = 0.026\ W/mK$; $\rho = 1.142\ kg/m^3$; $\nu = 15.630 \times 10^{-6}\, m^2/s$; $Pr = 0.713$.
[(CO5) (Solve/IOCQ)]

6 + 6 = 12

9. (a) A vertical cooling fin, approximating a flat plate $400\, mm$ high, is exposed to steam at atmospheric pressure. The fin is maintained at 90°C by cooling water. Assume the condensate film to be laminar. Determine the (i) rate of heat transfer per unit width of the fin and (ii) total rate of condensation.
Use the relation $\overline{Nu_L} = 0.943 \left[\frac{\rho(\rho - \rho_v) g\, h_{fg} L^3}{\mu k\, (T_g - T_W)}\right]^{0.25}$ for the average Nusselt number.
The properties of condensate (liquid water) evaluated at the mean film temperature are:
$\rho = 962\ kg/m^3$; $k = 0.677\ W/mK$; $\mu = 3.0 \times 10^{-4}\, kg/ms$
The values of ρ_v and h_{fg} at 100°C are also specified as follows:
$\rho_v = 0.598\ kg/m^3$; $h_{fg} = 2.27 \times 10^3\, kJ/kg$ [(CO6) (Formulate/HOCQ)]

(b) In a food processing plant, a brine solution is heated from 8°C to 14°C in a double-pipe heat exchanger by water. The water enters at 55°C and leaves at 40°C at the rate of $648\, kg/h\, (c_p = 4.18\ kJ/kgK)$. Take the overall heat transfer coefficient as $U = 800\ W/m^2K$. For the given data determine the area of heat exchanger required (i) for a parallel flow arrangement, and (ii) for a counter-flow arrangement. [(CO6) (Formulate/HOCQ)]

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

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	21.6%	52.8%	25.6%

Course Outcome (CO):

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

CO1	Identify the basic laws of heat transfer, and implement the concepts to account for the heat transfer in thermal analyses of engineering systems
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

Department & Section	Submission link:
ME-A	https://classroom.google.com/c/NDA1NjUzMDc5MzQ0/a/NDY0NDk2NDE3NzYw/details
ME-B	https://classroom.google.com/c/NDA1NjUzMDc5NDI1/a/NDY0NTI3ODQ0OTEw/details