HEAT TRANSFER
(MECH 3102)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

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

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) Choose the *wrong* statement out of the following:
(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.

(ii) A black surface at 227°C radiates heat at the rate of 30 W. At a temperature of 727°C, the rate of heat radiated in the same unit will be
(a) 120 (b) 240 (c) 480 (d) 120.

(iii) Good absorber of heat is a good radiator of heat also. This is
(a) Stefane's law (b) Kirchhoff's law (c) Wein's law (d) Plank's law.

(iv) Biot number is used in the analysis of
(a) lumped thermal capacity model
(b) steady state conduction
(c) steady state conduction and convection together
(d) radiation.

(v) 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.

(vi) The value of Prandtl number for air is about
(a) 0.1 (b) 0.3 (c) 0.7 (d) 1.7

(vii) The unit of overall coefficient of heat transfer is
(a) W/m^2K (b) W/m^2 (c) W/mK (d) W/m.

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

(ix) A sphere, a cube and a thin circular plate, all made of same material and having same mass are initially heated to a temperature of 250°C and then left in air at room temperature for cooling. Then, which one of the following is correct?
(a) All will be cooled at the same rate
(b) Circular plate will be cooled at lowest rate
(c) Sphere will be cooled faster
(d) Cube will be cooled faster than sphere but slower than circular plate.

(x) The properties of mercury at 300 K are: density = 13529 kg/m^3, specific heat at constant pressure = 0.1393 kJ/kg-K, dynamic viscosity = 0.1523 × 10^{-2} N.s/m^2 and thermal conductivity = 8.540 W/mK. The Prandtl number of the mercury at 300 K is
(a) 0.0248 (b) 2.48 (c) 24.8 (d) 248.

Fill in the blanks with the correct word

(xi) Minimum value of fin effectiveness is _____.

(xii) Lumped thermal capacity model is accepted for Bi < _____.

(xii) The unit of thermal resistance is _____.

(xiv) 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 _____.

(xi) Shape factor of a flat surface with respect to itself is _____.

Group - B

2. (a) What is the thickness required of a masonry wall having the thermal conductivity of 0.75 W/ (m K), if the steady rate of heat flow per unit surface area through it is to be 60 per cent of heat flow through a different structural wall having a thermal conductivity of 0.2 W/ (m K) and a thickness of 120 mm? Both the walls are of the same surface area and subjected to the same surface temperature difference. *[(CO2)(Relate/IOCQ)]*

(b) A long pipe carrying steam with OD = 250 mm has its outer surface temperature of T = 150°C. The pipe is exposed to an ambient with $T_\infty = 25$°C and a convective heat transfer coefficient of h = 50 W/m^2K. Calculate the thickness of asbestos insulation [$k = 0.1\ W/(m.K)$] required to reduce the heat loss by 50%.
[(CO2)(Judge/HOCQ)]

5 + 7 = 12

3. (a) The left and right walls of a 25 mm thick wall generating heat @ 40 MW/m^3 are at temperature 150°C and 100°C respectively. The thermal conductivity of the material of the wall is 200 W/m-K. Determine (i) the expression of the temperature in terms of distance (ii) the maximum temperature of the wall and

its location. (iii) Also determine the quantity of heat transfer per unit area from either side individually. *[(CO2)(Judge/HOCQ)]*

(b) Obtain an expression of critical radius of insulation referred to cylindrical geometry in standard terms. *[(CO2)(Apply/IOCQ)]*

7 + 5 = 12

Group - C

4. (a) A plane wall is fitted with an aluminium [$k = 204\ W/(m.K)$] pin fin of 2 cm diameter and 30 cm length. The fin base temperature is 300°C and the fin is in contact with air at 30°C. The convective heat transfer coefficient between the surface and air is 15 W/m^2K. Assuming the fin to be infinitely long, determine the temperatures at 10 cm and 20 cm from the base and the amount of heat convected out from the fin surface between these two points. *[(CO3) (Judge/HOCQ)]*

(b) Draw a transient temperature vs. time plot for a lumped system and indicate the time constant in the plot.
What is the expression of Biot number? Determine the characteristic length for a relatively large plate in terms of its dimension(s) for evaluating Biot number.
[(CO4)(Remember/LOCQ)]

6 + 6 = 12

5. (a) State and prove Kirchhoff's identity in radiation heat transfer. Make a comparison between a blackbody and a gray body. *[(CO3)(Remember/LOCQ)]*

(b) Obtain the reciprocity relationship in shape factor for radiation heat transfer.
An internal cylindrical enclosure has two circular surfaces marked 1 and 2; and a lateral curved surface marked 3. It is given that F_{12}= 0.12, write the complete shape factor matrix. *[(CO3)(Apply/IOCQ)]*

6 + 6 = 12

Group - D

6. (a) Engine oil at 55°C flows with a velocity of 1 m/s over a 5 m long flat plate whose temperature is 35°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)(Apply/IOCQ)]*

(b) Show physical significance of following non-dimensional numbers:
Pe (Peclet Number), St (Stanton Number). *[(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 30°C to 50°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 65°C. Determine the length of the tube required for fully developed flow.
Properties of water at 40°C:

$\rho = 995$ kg/m^3
$\nu = 0.657 \times 10^{-6}$ m^2/s
Pr = 4.340
k = 0.628W/mK
C_p = 4178J/kgK . *[(CO4)(Analyse/HOCQ)]*

(b) Superimpose hydrodynamic and thermal boundary layer profiles for Pr < 1, Pr = 1 and Pr > 1. *[(CO4)(Apply/IOCQ)]*

8 + 4 = 12

Group - E

8. (a) Water is heated by a 250 mm by 250 mm vertical flat plate which is maintained at 60°C. Find the rate of heat transfer when the water is at 20°C. At mean film temperature of T_f = (60 + 20)/2 = 40°C, the relevant physical parameters can be taken as k = 0.628 W/(m K), Pr = 4.34, ρ = 994.59 kg/m^3, ν = 0.658 x 10^{-6} m^2/s, β = 3 x 10^{-4} K^{-1}. Use Eq. $Nu = 0.59Ra_L^{1/4}$ (laminar flow) or Eq. $Nu = 0.1Ra_L^{1/3}$ (turbulent flow). *[(CO5)(Analyze/IOCQ)]*

(b) What is the difference between drop-wise condensation and film condensation? Which of the two is the more effective way of condensation and why? *[(CO5)(Understand/LOCQ)]*

8 + 4 = 12

9. (a) A counter-flow double-pipe heat exchanger is to heat water from 40°C to 100°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water available at 180°C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2.°C, determine the length of the heat exchanger required to achieve the desired heating. *[(CO6)(Analyze/IOCQ)]*

(b) Why is counter-flow Heat Exchanger more effective than a parallel flow heat exchanger? *[(CO6)(Understand/LOCQ)]*

8 + 4 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	25	45.8	29.2

Course Outcome (CO):

After the completion of the course 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.*