B.TECH/ME/5TH SEM/MECH 3102(BACKLOG)/2021

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) 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 [(CO2) (Apply/IOCQ)]
(a) 20 kW (b) 42 kW (c) 84 kW (d) 126 kW.

(ii) For a long solid cylinder of radius R with uniform volumetric heat generation, the temperature distribution in the dimensionless form is given by $\frac{T-T_w}{T_{max}-T_w}$ = [(CO1) (Remember/LOCQ)]
(a) $1-\frac{r}{R}$ (b) $1-(\frac{r}{R})^2$ (c) $1-(\frac{r}{R})^3$ (d) $1-(\frac{r}{R})^4$

(iii) When does the general heat conduction equation which gives the temperature distribution and conduction heat flow in an isotropic solid reduce to Laplace equation? [(CO1) (Remember/LOCQ)]
(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.

(iv) Thermal conductivity is maximum for the substance [(CO1)(Remember/LOCQ)]
(a) Silver (b) Ice (c) Aluminium (d) Diamond.

(v) Consider two metal plates pressed against each other. Other things being equal, which of the measures below will cause the thermal contact resistance to increase? [(CO2)(Apply/IOCQ)]
(a) Cleaning the surfaces to make them more shiny
(b) Pressing the plates against each other with a greater force
(c) Filling the gap with a conducting fluid
(d) Coating the contact surfaces with a thin layer of soft metal like tin.

(vi) The ratio of the heat transfer rate at the surface to the heat transport rate by the fluid by its thermal capacity is [CO4]/(Understand/LOCQ)]

(a) Peclet number (b) Stanton number
(c) Nusselt number (d) Grashoff number.

(vii) For *forced* convection heat transfer, the Nusselt number is a function of [(CO4)/(Understand/LOCQ)]

(a) Prandtl number and Biot number
(b) Reynolds number and Grashof number
(c) Prandtl number and Grashof number
(d) Reynolds number and Prandtl number.

(viii) In a fully developed laminar flow through a tube, consider the following statements: [CO5]/(Understand/LOCQ)]

(I) $\frac{\partial u}{\partial x} = 0$
(II) $\frac{\partial T}{\partial x} \neq 0$ at any radius r
(III) temperature profile T(r) continuously changes with x
(IV) for constant wall temperature of tube, the surface heat flux is constant.
Out of the above statements

(a) only (I) and (II) are correct (b) only (I) and (IV) are correct
(c) (I), (II), and (III) are correct (d) all four are correct.

(ix) The Grashof number can be represented as [(CO5)/ (Understand/LOCQ)]

(a) $\frac{\text{Inertia force}}{\text{Buoyancy force}}$ (b) $\frac{\text{Buoyancy force}}{\text{Inertia force}}$
(c) $\frac{(\text{Viscous force})(\text{Buoyancy force})}{(\text{Inertia force})^2}$ (d) $\frac{(\text{Inertia force})(\text{Buoyancy force})}{(\text{Viscous force})^2}$

(x) For a balanced heat exchanger ($\dot{m}_h c_h = \dot{m}_c c_c$), the temperature profiles of the two fluids along the length of the heat exchanger are [CO6]/(Understand/LOCQ)]

(a) linear and non-parallel (b) non-linear and parallel
(c) linear and parallel (d) parabolic.

Group – B

2. (a) The top surface of a horizontally placed metal plate is exposed to ambient air at T_∞ = 20°C and an incident solar radiation flux of 900 W/m². The specific heat and density of the metal plate are 900 J/kg-K, and 2700 kg/m³, respectively. The thickness of the plate is 4 mm and its bottom surface is completely insulated. It is known that the top surface absorbs 80% of the incident solar radiation as a result of a special, thin coating applied to it. Disregard any radiation heat loss from the plate. The convective heat transfer coefficient between the surface and the air is 20 W/m²-K. What is the steady state temperature of the plate? What is the rate of rise in temperature at the instant when the temperature of the plate is 40°C before reaching steady state? [(CO2)(Evaluate/HOCQ)]

(b) The left and the right sides of a large vertical plane are maintained at 120°C and 50°C, respectively in a steady state heat transfer. Thickness of the plane is 0.2 m and its thermal conductivity is 1.2 W/m-K. Find the location of the plane which is at 100°C. If the surface area of the plane is 15 m^2, what is the steady rate of heat transfer? [(CO2)(Understand/LOCQ)]

8 + 4 = 12

3. (a) Steady-state 1-D heat transfer is occurring through an infinite plane wall with heat generation. Thermal conductivity is known to be 50 W/m-°C and thickness is 50 mm. The temperature plot was found to be $\boldsymbol{T = \alpha + \beta x^2}$, where $\boldsymbol{\alpha}$ = 200°C, $\boldsymbol{\beta}$ = - 2000°C/ m^2, T is in degrees Celsius and x in meters along the thickness.
   (i) What is the heat generation rate in the plane?
   (ii) Determine the heat fluxes at the two wall faces. [(CO2) (Evaluate/HOCQ)]

   (b) Two thin rods each of length $\boldsymbol{L}$ ($\boldsymbol{L >> D}$) and diameter D are joined together to form a rod of length $\boldsymbol{2L}$. Thermal conductivity of one rod is $\boldsymbol{k_1}$ and that of the other is $\boldsymbol{k_2}$. There is no heat transfer in the radial direction as the lateral surface of the combined rod is insulated. Ignore any contact resistance. What is the effective thermal conductivity of the composite rod for axial heat transfer? [(CO2) (Apply/IOCQ)]

6 + 6 = 12

Group – C

4. (a) A constantan wire of 1 mm diameter originally at 25°C is suddenly exposed to hot air at 25°C. If the convection heat transfer coefficient is 3 W/m^2-K, what will be time required for the wire temperature to reach 225°C? [For constantan, thermal conductivity k = 22.7 W/m-K, thermal diffusivity $\alpha = 0.612\times 10^{-5}$ m^2/s] [(CO3) (Remember/LOCQ)]

   (b) A rectangular fin of length 30 cm, width 30 cm and thickness 2 mm is attached to a hot surface at 300°C. The fin is made of aluminium (k = 204 W/m-K) and is exposed to air at 30°C. The fin end is un-insulated and can lose heat through its end surface also. The convection heat transfer coefficient between the fin surface and air is 15 W/m^2-K. What is the length correction that must be added to the length so that the result for insulated end can be used? With so done, what is the temperature at the end and what is the total heat transfer from the fin? [(CO3)(Analyze/IOCQ)]

4 + 8 = 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/IOCQ)]

   (b) Consider the internal faces of a cube forming a complete enclosure. Designate the six surfaces by 1,2, ...6. It is given the shape factor of any face with respect to its parallel face is 0.2, what is the value of shape factor of a face with respect to a face inclined at 90°?
   A very long duct has been prepared with 3 long rectangular plates of same dimension so that the cross section is an equilateral triangle. What is the value

of shape factor of any internal face with respect to any other internal face? [(CO3) (Analyze/IOCQ)]

6 + (4 + 2) = 12

Group – D

6. (a) Write the pertinent dimensionless terms governing the phenomenon of (i) forced convection and (ii) free convection.[(CO4) (Explain/LOCQ)]

(b) Air flows with a velocity of U_∞ and temperature of T_∞ over a flat plate. The plate is maintained at a constant temperature $T_W (T_W > T_\infty)$. The temperature distribution in the thermal boundary layer is given by

$$\frac{T_W - T}{T_W - T_\infty} = 2\left(\frac{y}{\delta_t}\right) - \frac{1}{2}\left(\frac{y}{\delta_t}\right)^3$$

[y: distance normal to the surface; δ_t: thickness of the thermal boundary layer]. If δ is the hydrodynamic boundary layer, and it is given that $(\delta_t/\delta) = 1$ and $(\delta/x) = 5.0Re_x^{-0.5}$, show that the local Nusselt number ($= Nu_x$) is given by $Nu_x = 0.4Re_x^{0.5}$. [(CO4)(Examine/IOCQ)]

(3 + 3) + 6 = 12

7. (a) Define (i) hydrodynamic boundary layer and (ii) thermal boundary layer. [(CO4)(Explain /LOCQ)]

(b) A fluid flows through a pipe of diameter D with an average flow velocity of U_0. The tube is heated from an external source in such a way that the inner surface of the tube is kept at a constant temperature T_W over the entire length L of the tube. The bulk mean temperatures of the fluid at inlet to and outlet from the tube are T_{b1} and T_{b2} respectively. Show that the average Nusselt number Nu_L over the length of the tube L is given by:

$$\overline{Nu_L} = \frac{1}{4}\frac{RePr}{(L/D)} ln\left[\frac{T_W - T_{b1}}{T_W - T_{b2}}\right]$$

The Reynolds number Re is defined as $Re = \rho U_0 D/\mu$. Consider the properties of fluid to be constant. Neglect axial conduction. [(CO4) (Analyze /IOCQ)]

(3 + 3) + 6 = 12

Group – E

8. (a) Air at atmospheric pressure is required to flow over a circuit board to cool the electronic elements mounted on it. Let us consider a chip of length 3 mm and width 3 mm located 0.1 m from the leading edge. The board surface is irregular, and the local Nusselt number correlation is given by $\mathrm{Nu_x} = 0.06\mathrm{Re_x^{0.85}}\mathrm{Pr^{0.33}}$. The chip has to dissipate 50 mW of energy while its surface temperature has to be kept below 45°C What is the minimum flow velocity of air required for the purpose?

Assume the free stream temperature of air to be 25°C For air:

$\rho = 1.2\ \mathrm{kg/m^3}$; $\mu = 1.8 \times 10^{-5}\ \mathrm{Ns/m^2}$; $c_p = 1000$ J/kg°C; $k = 0.03$ W/mK

[(CO4) (Evaluate/HOCQ)]

(b) A vertical plate is maintained at 40°C in still air at 20°C Determine the height at which the boundary layer will turn turbulent, if the turbulence sets in at $\mathrm{Gr.Pr} = 10^9$.
The properties of air at the film temperature are:
$$\nu = 16 \times 10^{-6}\ \mathrm{m^2/s}\ , \rho = 1.165\ \mathrm{kg/m^3}\ , \mathrm{Pr} = 0.71.$$
Repeat the problem for water flow at the same film temperature. The properties of water are:
$$\nu = 0.8315 \times 10^{-6}\ \mathrm{m^2/s}\ , \beta = 0.31 \times 10^{-3} \mathrm{K^{-1}}\ , \mathrm{Pr} = 0.71.$$
In which case does the turbulence set in at a shorter distance? Why?
[(CO5) (Apply/IOCQ)]

4 + 8 = 12

9. (a) 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)(Evaluate/HOCQ)]

(b) Hot oil $\left(c_p = 2.09\ \mathrm{kJ/kgK}\right)$ flows through a counter-flow heat exchanger at the rate of $2520\ \mathrm{kg/h}$. The oil enters at 200°C and leaves at 70°C Cold oil $\left(c_p = 1.67\right.$ kJkgK exits the system at 150°C at the rate of 1.2kgs.

(I) Determine the surface area of the heat exchanger required for the purpose, if the overall heat transfer coefficient is $U = 650\ \mathrm{W/m^2K}$

(II) Suppose that the above heat exchanger, when new, transfers 15% more heat than it does after being in service for six months. Assuming that it operates between the same temperature differentials and that there is insufficient scale build-up to change the effective surface area, determine the fouling factor in terms of its clean (new) overall heat transfer coefficient. [(CO6)(Evaluate/HOCQ)]

(2 + 2) + (5 + 3) = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	26.4%	45.3%	28.3%

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 - Backlog	https://classroom.google.com/c/NDY0NTI4OTY4NDcz/a/NDY0NTI4OTY5MTMz/details
	Class code: tqyiw7q