# 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) The critical radius of insulation in cylindrical geometry with usual notations is
(a) $\frac{k}{h}$ (b) $\frac{2k}{h}$ (c) $\frac{k}{2h}$ (d) none of these

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

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

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

(v) Suppose that a hot metal ball is immersed in a large pool of cold water, then temperature distribution in the body depends only upon
(a) thermal conductivity of the body
(b) thermal conductivity of water
(c) convective heat transfer from the body surface to water
(d) both (a) and (c)

(vi) What is the basic equation of radiation from which all other equations of radiation can be derived?
(a) Stefane- Boltzman equation (b) Wien's equation
(c) Planck's equation (d) Raleigh-Jean's equation.

(vii) The properties of mercury at 300 K are: density = 13529 $kg/m^3$, specific heat at constant pressure = 0.1393 kJ/kgK, dynamic viscosity = $0.1523 \times 10^{-2}$ $Ns/m^2$ 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

(viii) For the fully developed laminar flow and heat transfer in a uniformly heated long circular tube, if the flow velocity is doubled and the tube diameter is halved, the heat transfer coefficient will be
(a) double of the original value (b) half of the original value
(c) same as before (d) four times of the original value.

(ix) 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) $gD^3\beta\Delta tP^2/\mu$

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

*Fill in the blanks with the correct word*

(xi) The unit of thermal resistance is _________.

(xii) In free convection heat transfer, the Nusselt number is a function of fluid Prandtl number and_______.

(xiii) For calculation of heat transfer by natural convection from a horizontal cylinder, the characteristic length in Grashoff Number is _______ of the cylinder.

(xiv) _________ represents dimensionless temperature gradient at the surface.

(xv) 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 _________.

## Group - B

2. (a) A cylindrical cement tube of radii 0.05 cm and 1.0 cm has a wire embedded into it along its axis. To maintain a steady temperature difference of 120° C between the inner and outer surfaces, a steady current of 5 ampere is required to flow in the wire. Take resistance of wire equal to 0.1 ohm per cm of length. Find (i) the amount of heat generated per meter length (ii) the thermal conductivity of the material of the tube. *[(CO2)(Analyse/IOCQ)]*

(b) Identify the different modes of heat transfer in the following systems/operations.
(i) Steam raising in a steam boiler
(ii) Condensation of steam in a condenser
(iii) Heat loss from a vacuum flask
(iv) Heating of water in a bucket with an immersion heater. *[(CO1)(Remember/LOCQ)]*

**6 + 6 = 12**

3. (a) Derive an expression of steady state heat conduction (without any generation) assumed one directional along the axial direction of a truncated cone of radii $r_1$, $r_2$, length L, temperatures at the two ends $T_1$, $T_2$, andthermal conductivity k. The lateral surface is perfectly insulated. For the given values $r_1$= 75 mm, $r_2$ = 125 mm, $T_1$=50° C, $T_2$ = 550°C, L = 0.3 m, k = 230 $W/m.K$, find the rateof heat transfer. *[(CO2)(Apply/IOCQ)]*

(b) In a composite slab of two materials, thickness of one (thermal conductivity $k_1$) is twice that of the other (thermal conductivity $k_2$). The temperature at the interface is the average of those at two ends under steady 1-d heatconduction. Determine the ratio $k_1/k_2$. *[(CO2)(Apply/IOCQ)]*

**8 + 4 = 12**

## Group - C

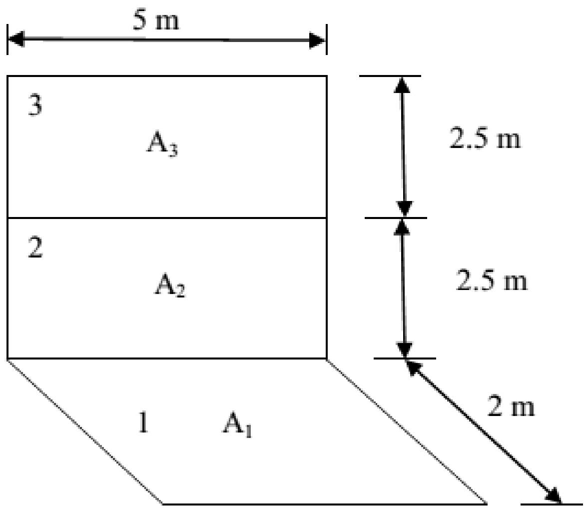
4. (a) What is meant by view factor and why is it so important in calculation of radiation heat transfer? Consider a furnace with a hemispherical dome (surface1) and a flat circular base (surface 2) of diameter ***D***. Determine the complete view factor matrix. *[(CO3)(Apply/IOCQ)]*

(b) A solid copper ball of 20 cm diameter initially at a uniform temperature of 250°$C$ is suddenly immersed in a well stirred fluid which is maintained at a uniform temperature of 40°$C$. The convective heat transfer coefficient between the sphere and the fluid is200 $W/m^2.K$. Determine (i) the Biot number to satisfy that lumped capacity method can be applied. (ii) the temperature of the sphere at 5, 10, 20 minutes of immersion. Following data for the ball material are given: density = 8954 $kg/m^3$; specific heat = 383 $J/kg.K$; thermal conductivity = 386 $W/m.K$. *[(CO3)(Apply/IOCQ)]*

**6 + 6 = 12**

5. (a) Given, the total emissive power for a black body radiation $\mathbf{E_b} = \frac{2\pi hc^2}{\lambda^5\left\{e^{hc/\lambda kT} - 1\right\}}$, derive the mathematical expression of Wein's displacement law. Hence write the statement of the law. *[(CO3)(Analyse/HOCQ)]*

(b) For the surfaces shown below, determine the shape factors $F_{13}$ and $F_{31}$, given that $F_{1-2,3}$= 0.31 & $F_{1-2}$= 0.27.




*[(CO3)(Apply/IOCQ)]*

**6 + 6 = 12**

## Group - D

6. (a) Air at 25°C flows past a flat plate at 2.5 m/s. The plate measures 600 mm × 300 mm and is maintained at a uniform temperature at 95°C. Calculate the heat loss from the plate if the air flows parallel to the 600 mm side.
Take properties of air at $T_f$ = 60°C:
Pr = 0.696
$\nu = 1897 \times 10^{-6}$ m$^2$/s
k = 0.02896 W/Mk. *[(CO4)(Analyze/IOCQ)]*

(b) By dimensional analysis show that for forced convection heat transfer the Nusselt number (Nu) can be expressed as a function of Prandtl number (Pr) and Reynolds number (Re). *[(CO4)(Create/HOCQ)]*

**6 + 6 = 12**

7. (a) 250 kg/hr of air is cooled from 100°C to 30°C by flowing through a 3.5 cm inner diameter pipe. Calculate the value of heat transfer coefficient if the properties of air at 65° C are $\rho$= 1.044 kg/m$^3$; $\mu$= 0.003 kg/(m hr); $k$ = 0.0298 W/(m K); Pr = 0.7
Use Equation $Nu = 0.023(Re)^{0.8}(\mathrm{Pr})^{0.3}$, if theflow is turbulent. *[(CO4)(Apply/IOCQ)]*

(b) Show physical significance of Following non-dimensional numbers:
Nu (Nusselt Number), Pr (Prandtl Number), and Re (Reynolds Number). *[(CO4)(Remember/LOCQ)]*

**6 + 6 = 12**

## Group - E

8. (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)(Analyse/IOCQ)]*

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

**8 + 4 = 12**

9. (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$^3$, $\nu = 0.658 \times 10^{-6}$ m$^2$/s, $\beta = 3 \times 10^{-4}$ K$^{-1}$. 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)(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**

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| Cognition Level | LOCQ | IOCQ | HOCQ |
|---|---|---|---|
| Percentage distribution | 20.83 | 66.67 | 12.5 |