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 ratio of total emissive power of a body to the total emissive power of a black body is called
(a) absorptivity (b) reflectivity
(c) transmissivity (d) emissivity.

(ii) The ratio of momentum and thermal diffusivity of the fluid is represented by
(a) Reynolds number (b) Nusselt number
(c) Stanton number (d) Prandtl number.

(iii) The SI unit of thermal diffusivity is
(a) m^{-2} (b) m^{-1} (c) W/m^2 (d) m^2/s.

(iv) In natural convection heat transfer, the Nusselt number is a function of fluid Prandtl number and
(a) Biot number (b) Reynolds number
(c) Grashoff number (d) Stanton number.

(v) The thermal resistance for $1-D$ heat conduction through a hollow sphere of inner and outer radii r_1 and r_2 with thermal conductivity k is
(a) $\frac{r_2-r_1}{4\pi k r_1 r_2}$ (b) $\frac{k(r_2-r_1)}{4\pi r_1 r_2}$
(c) $\frac{4\pi k(r_2-r_1)}{r_1 r_2}$ (d) $\frac{(r_2-r_1)r_1 r_2}{4\pi k}$.

(vi) Which of the following represents dimensionless pressure drop for internal flow?
(a) Stanton number (b) Fourier number
(c) Friction factor (d) Peclet number.

(vii) Identify the wrong statement in respect of thermal time constant in Lumped Capacitance Method:
(a) its expression is $\frac{\rho V c}{hA}$
(b) it has the unit of time
(c) higher the value faster the response towards sudden change in environment temperature
(d) higher the value slower the response towards sudden change in environment temperature.

(viii) The Nusselt number signifies
(a) dimensionless velocity gradient at the surface
(b) dimensionless temperature gradient at the surface
(c) ratio of inertia and viscous force
(d) fluid property.

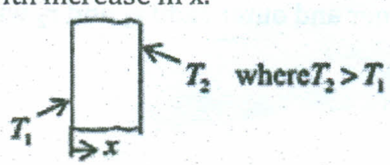
(ix) The laminar boundary layer thickness at any distance x from the leading edge of a flat plate varies as
(a) Re_x^{-1} (b) $Re_x^{-0.5}$ (c) $Re_x^{0.5}$ (d) Re_x^2.

(x) The value of Pr for air is about
(a) 0.1 (b) 0.4 (c) 0.71 (d) 1.1.

Group – B

2. (a) Define thermal conductivity. What is meant by thermal resistance? Derive an expression of the thermal resistance of a composite wall of three layers with appropriate parameters.

(b) Consider one-dimensional steady heat conduction without heat generation through a plane wall with the boundary conditions, as shown in the Fig. The thermal conductivity is $k = k_0 + bT$ where k_0 and b are positive constants and T is in Kelvin. Determine whether the temperature gradient $\left(\frac{dT}{dx}\right)$ increases, decreases or remains constant with increase in x.



(1 + 1 + 4) + 6 = 12

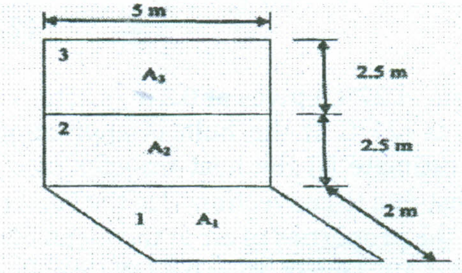
3. (a) What is meant by critical thickness of insulation referred to a cylindrical geometry? Derive an expression of the critical insulation radius and explain its significance for a cylindrical geometry.

(b) Thermal energy is generated at a constant rate of $q_0 = 2 \times 10^6$ W/m³ in a copper rod of radius r = 50 mm with the two flat faces perfectly insulated. The thermal conductivity k = 386 W/m-K. The rod is cooled by convection from its cylindrical surface into an ambient at 25⁰ C with a heat transfer coefficient h = 1000 W/m²-K. What is the surface temperature of the rod at steady state? What is the maximum temperature of the rod?

6 + 6 = 12

Group – C

4. (a) For the surfaces shown below write the complete shape factor matrix $[F_{ij}]$, given that $F_{1-2,3} = 0.31$, $F_{1-2} = 0.27$.



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

6 + (4 + 2) = 12

5. (a) A solid copper ball of 100 mm diameter and ρ = 8954 kg/m³, c_p = 383 J/kg-K, k = 386 W/m-K is at a uniform temperature of 250⁰ C. It is suddenly immersed in a well-stirred fluid which is maintained at a uniform temperature of 50⁰ C. The convective heat transfer coefficient h between the ball and the fluid = 200 W/m²-K. Estimate the time after which the ball reaches a temperature of 100⁰C.

(b) A 2 cm thick steel slab heated to 525°C is held in air stream having a mean temperature of 25°C. Estimate the time interval when the slab temperature would not depart from the mean value of 25°C by more than 0.5°C at any point in the slab.
The steel plate has following thermo-physical properties:
$\rho = 7950\ kg/m^3, c_p = 455\ J/kgK, k = 46\ W/mK.$
The heat transfer coefficient on plate surface $h = 36\ W/m^2K.$

6 + 6 = 12

Group – D

6. (a) What is the significance of the *critical* Reynolds number? State its approximate values for flow over a flat plate and through a circular tube.

(b) Where is the local heat flux higher for laminar external forced convection over a flat plate-at the leading edge or at the trailing edge?

(c) Air at 27°C and 1 atm flows over a heated flat plate with a velocity of 2 m/s. The plate is at uniform temperature of 60°C. Calculate the heat transfer rate from (i) first 0.2 m of the plate, and (ii) first 0.4 m of the plate. (Assume the properties of air at the mean film temperature as: $\nu = 17.36 \times 10^{-6}\, m^2/s, k_f = 0.02749\ W/mK, Pr = 0.71, c_p = 1.006\, kJ/kgK$.)

(2 + 1 + 1) + 2 + (3 + 3) = 12

7. (a) Air stream at 27°C moves at 0.3 m/s across a 100 W incandescent bulb glowing at 127°C. If the bulb is approximated as a 60 mm diameter sphere, estimate (i) the heat transfer rate, and (ii) the percentage of power lost due to convection. Use the correlation $\mathrm{Nu} = 0.37\mathrm{Re}_D^{0.6}\mathrm{Pr}^{0.3}$. Assume the properties of air at the mean film temperature as: $\nu = 2.09 \times 10^{-5}\, \mathrm{m^2/s}, \mathrm{k_f} = 0.03\, \mathrm{W/mK}, \mathrm{Pr} = 0.71$.

(b) What is the physical significance of the Prandtl number?

(c) Explain the Reynolds Colburn analogy for laminar external forced convection over a flat plate.

(4 + 2) + 2 + 4 = 12

Group – E

8. (a) The wall of a tube 4 m long and 20 mm diameter is held at constant temperature by providing a steam jacket. A viscous fluid enters the tube at 30°C and leaves at 40°C at the rate of 180 kg/hr. Determine (i) the average heat transfer coefficient, and (ii) the wall temperature. Use the following correlation: $\mathrm{Nu} = 3.65 + \frac{0.67\frac{d}{l}\mathrm{RePr}}{1+0.04\left(\frac{d}{l}\mathrm{RePr}\right)^{0.67}}$.

Take the following thermophysical properties of the fluid: $\rho = 850\frac{\mathrm{kg}}{\mathrm{m^3}};\ \mathrm{k} = 0.1396\ \mathrm{W/mK};\ \nu = 5.1 \times 10^{-6}\, \mathrm{m^2/s}\ ;\ \mathrm{c_p} = 2000\frac{\mathrm{J}}{\mathrm{kgK}}$

(b) Estimate the heat transfer from a 40 W incandescent bulb at 125°C to 25°C in quiescent air. Approximate the bulb as a 50 mm diameter sphere. At the mean film temperature of 75°C, the thermo-physical properties of air are: $\mathrm{k} = 0.03\ \mathrm{W/mK};\ \nu = 20.55 \times 10^{-6}\, \mathrm{m^2/s}\ ;\ \mathrm{Pr} = 0.693$.

[redacted]

Using the correlation for convection coefficient $\mathrm{Nu} = 0.60(\mathrm{Gr.Pr})^{0.25}$, calculate the percentage of power lost by free convection.

6 + 6 = 12

9. (a) A steam pipe 50 mm diameter and 2.5 m long has been placed horizontally and exposed to still air at 25°C. If the pipe wall temperature is 295°C, determine the rate of heat loss. At the mean temperature of 160°C, the thermo-physical properties of air are:
$k = 0.0364\ W/mK$; $\nu = 30.09 \times 10^{-6}\ m^2/s$; $Pr = 0.682$.
For laminar flow over horizontal cylinders within the range $10^3 < Gr.Pr < 10^9$, use the correlation $Nu = 0.53(Gr.Pr)^{0.25}$.

(b) A heat exchanger is required to cool 55000 kg/hr of alcohol from 66°C to 40°C using 40000 kg/hr of water entering at 5°C. Calculate the (i) exit temperature of water (ii) heat transfer rate (iii) surface area required for parallel-flow type and (iv) counter-flow type of heat exchanger.
Take the overall heat transfer coefficient U = 580 W/m^2k,
$C_{Palc} = 3760\ J/Kgk$,
$CP_{wat} = 4180\ J/Kgk$

6 + (1.5 × 4) = 12