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) In M-L-T-θ system (T being time and θ being temperature), what is the dimension of thermal conductivity?
(a) $ML^{-1}T^{-1}\theta^{-3}$ (b) $MLT^{-1}\theta^{-1}$ (c) $MLT^{-3}\theta^{-1}$ (d) $MLT^{-2}\theta^{-1}$.

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

(iii) Two walls of same thickness and cross sectional area have their thermal conductivities in the ratio of 1:2. If the same temperature difference is maintained across the wall faces the ratio of heat flow Q_1/Q_2 will be
(a) 1:2 (b) 1:1 (c) 2: 1 (d) 4:1.

(iv) Which one of the following expresses the thermal diffusivity of a substance in terms of thermal conductivity k, mass density ρ and specific heat c?
(a) $\rho^2 k c$ (b) $1/(\rho k c)$ (c) $k/(\rho c)$ (d) $(\rho c)/k$.

(v) Identify the incorrect statement in respect of a fin with insulated tip:
(a) its tip is insulated
(b) at its tip the temperature gradient is zero
(c) its tip may be called adiabatic
(d) the tip temperature is same as ambient temperature.

(vi) A fluid is flowing over a stationary flat plate. To move another plate above the flat plate at a distance y with a speed u_0 the necessary force is proportional to
(a) the speed u_0 (b) the inverse of y
(c) the dynamic viscosity of fluid (d) all of the above.

(vii) The value of shape factor of a surface with respect to itself is zero except for the following surface

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

(viii) 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

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

(ix) Consider the following statements in relation to a fully developed laminar flow through a tube,

(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) only (I), (II), and (III) are correct (d) all four are correct.

(x) In a two-fluid heat exchanger, the inlet and outlet temperatures of the hot fluid are 65°C and 40°C respectively. For the cold fluid, these values are 15°C and 43°C respectively. The system is a

(a) parallel flow heat exchanger
(b) counter flow heat exchanger
(c) heat exchanger where both parallel flow and counter flow operations are possible
(d) cross flow heat exchanger.

Group – B

2. (a) Three rectangular slabs A, B and C are joined together (in series). There is no thermal contact resistance at the interfaces. The centre slab B experiences a non uniform internal heat generation with an average value equal to 10000 W/m^3, while the left slab A and the right slab C have no internal heat generation. All slabs have thickness equal to 1 m and equal thermal conductivity of 5 W/m-K. The two extreme faces are exposed to fluid with heat transfer coefficient of 100 W/m^2-K and bulk temperature 30 °C. The heat transfer in the slabs is assumed to be one dimensional and steady with all properties constant. If the left extreme temperature T_1 is measured to be 100 °C, what is the right extreme face temperature T_2? What are the temperatures in the left and right interfaces?

(b) A 2.0 mm diameter wire is maintained at a temperature of 500 °C and is exposed to a convection environment at 30 °C with h = 150 W/(m^2 K). Calculate the thermal conductivity which will cause an insulation thickness of 0.25 mm to produce a 'critical radius'. With this value of thermal conductivity, what should be the insulation thickness to reduce the heat transfer by 50 % from that experienced by the bare wire?

6 + 6 = 12

3. (a) An infinite composite vertical slab is made of two layers of different materials. The left layer is 5 cm thick, has thermal conductivity $\boldsymbol{k_l = 0.4(1 + 0.07t)}$ **W/m-k** and its exposed surface is insulated, where $\boldsymbol{t}$ is the temperature at any point in °C. The right layer is 2.5 cm thick, has thermal conductivity 25 W/m-K and its outside surface is exposed to a fluid at 20°C where the convective heat transfer coefficient is 32 W/m^2.The temperature at the interface between the two layers is estimated to be 60°C.
Assuming 1D steady heat transfer across the slab, determine
(i) rate of heat flux from the slab to the fluid
(ii) temperature at the insulated surface.

(b) A 3 mm diameter and 5 m long electric wire is tightly wrapped with a 2 mm thick plastic cover whose thermal conductivity is k = 0.15 W/m-K. Electrical measurements indicate that a current of 10 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is exposed to a medium at $T_\infty = 30^0C$ with a heat transfer coefficient h = 12 W/m^2-K, determine the temperature at the interface of wire and plastic cover in steady operation. Also determine whether doubling the thickness of the plastic cover will increase or decrease the interface temperature.

6 + 6 = 12

Group – C

4. (a) An egg assumed spherical with a mean diameter of 4 cm initially at 25°C is placed in a pan of boiling water at 100°C for 4 minutes and found to be boiled to the consumer's taste. For how long it needs to be boiled for the same result if it is taken from a refrigerator at 5°C? Thermal conductivity, density and specific heat of egg are: 12 W/m-K; 1250 kg/m^3 and 4 kJ/kg-K respectively. Convective heat transfer coefficient for the system is 125 W/m^2-K

(b) A carbon steel rod (k = 55 W/m-K) has been attached to a plane wall maintained at a temperature of 350°C. The rod is 8 cm long and its cross section is an equilateral triangle of side 5 mm. Determine the heat dissipation from the rod if it is exposed to an environment at 25°C with convective heat transfer coefficient of 100 W/m^2-K. Consider the end surface loss to be negligible.

6 + 6 = 12

5. (a) The surface of a blackbody is at 600 K. Obtain the wave length at which maximum monochromatic emission takes place. What would be the emissive power of a grey body with emissivity 0.8 at the same temperature?
Thermal radiation strikes a surface which has a reflectivity of 0.55 and a transmissivity of 0.032. The absorbed flux as measured indirectly by heating effect works out to be 83.6 W/m2. Determine the rate of incident flux.

(b) A 30 mm diameter spherical container used for storing liquid nitrogen under atmospheric condition at 90 K is insulated by enclosing concentrically within another spherical shell of 45 cm diameter with negligible thickness. The intervening annular space between the two spherical surfaces is completely evacuated. The surface emissivity of both the surfaces is 0.3. Make calculation for the radiant heat flow rate if the temperature of the outer container is 300 K. What changed value of emissivity of the outer surface will reduce the heat transfer rate by 20%?

6 + 6 = 12

Group – D

6. (a) Air at a temperature of T_∞ flows over a stationary flat plate with a free stream speed of u_∞. The plate is maintained at a constant temperature of T_W. The velocity u and temperature T of air at any location are respectively given by (symbols carry their usual meanings)

$$\frac{u}{u_\infty} = \sin\frac{\pi}{2\delta};\ \frac{T-T_W}{T_\infty - T_W} = 2\left(\frac{y}{\delta_t}\right) - \left(\frac{y}{\delta_t}\right)^3$$

Find the ratio of the heat transfer coefficient to the shear stress at the plate surface using the following data:

$$u_\infty = 9\ m/s;\ \frac{\delta}{\delta_t} = Pr^{0.33};\ T_W = 200°C;\ T_\infty = 50°C;$$

$$\mu_{air} = 2.5 \times 10^{-5}\ Ns/m^2;\ k_{air} = 0.04\ W/mK;\ c_{p,air} = 1\ kJ/kgK$$

(b) The velocity distribution in a laminar boundary layer is given by $\frac{u}{U} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^2$, where u is the velocity at a distance y from the plate and $u = U$ at $y = \delta$. If δ denotes the boundary layer thickness, calculate the ratio of the momentum thickness to the boundary layer thickness $\left(\frac{\theta}{\delta}\right)$.

8 + 4 = 12

7. (a) Experimental results indicate that the local heat transfer coefficient h_x for flow over a flat plate with an extremely rough surface is approximated by the relation $h_x = Cx^{-0.16}$, where C is a constant coefficient and x is the distance from the leading edge of the plate. Set up a relation between the local heat transfer coefficient and the average heat transfer coefficient $\bar{h}$ over any plate length x.

(b) Show by the method of dimensional analysis that for forced convection heat transfer, the Nusselt number is a function of the Reynolds number and the Prandtl number.

Calculate the rate of heat loss from a human body, which may be considered as a vertical cylinder $30\ cm$ diameter and $175\ cm$ high while standing in $30\frac{km}{hr}$ wind at $15°C$. The surface temperature of the human is $35°C$. At the mean film temperature of $25°C$, the thermo-physical properties of air are:

$k = 0.0263\ W/mK;\ \nu = 15.33 \times 10^{-6}\ m^2/s;\ Pr = 0.7.$

For $Re < 5 \times 10^5$, use the correlation $Nu = 0.664 Re^{0.5} Pr^{0.33}$.

3 + (5 + 4) = 12

Group – E

8. (a) What do you mean by Boussinesq approximation? What is the physical significance of Grashof number with reference to heat transfer by natural convection?

(b) A metal plate of length $0.609\ m$ forms the vertical wall of an oven. The plate is at a uniform temperature of $171°C$. Within the oven is air at $93.4°C$ and atmospheric pressure. Assume air as an ideal gas ($R = 0.287\ kJ/kgK$) and that natural convection conditions hold near the plate. For this case consider the correlation
$Nu = 0.548\ (GrPr)^{0.25}$
Find **(i)** the mean heat transfer coefficient and **(ii)** the heat taken up by air per second per unit width.
Take the following properties of air at the film temperature:
$c_p = 1.005\ kJ/kgK;\ \ k = 0.0332\ W/mK;\ \ \mu = 23.2 \times 10^{-6}\ Ns/m^2$.

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

9. (a) The wall of a tube $4.1\ m$ long and $22\ mm$ 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: $Nu = 3.65 + \frac{0.67\frac{d}{l}RePr}{1+0.04\left(\frac{d}{l}RePr\right)^{0.67}}$.
Take the following thermophysical properties of the fluid:
$\rho = 850\frac{kg}{m^3};\ k = 0.1396\ W/mK;\ \nu = 5.1 \times 10^{-6}\ m^2/s\ ;\ c_p = 2000\frac{J}{kgK}$

(b) Estimate the heat transfer from an $40\ W$ incandescent bulb at $127°C$ to $23°C$ 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:
$k = 0.03\ W/mK\ ;\ \nu = 20.55 \times 10^{-6}\ m^2/s\ ;\ Pr = 0.693$.
Using the correlation for convection coefficient $Nu = 0.60(Gr.Pr)^{0.25}$, calculate the percentage of power lost by free convection.

6 + 6 = 12

Department & Section	Submission link:
ME A	https://forms.gle/vceNq7vFz2Vbh9ct8
ME B	https://forms.gle/A2sgPEP8UuoJs9Ec6