Ref. No.: Ex/PG/PE/T/113A/2024

Master of Power Engineering, 1st Semester Examination, 2024

Heat and Mass Transfer

Time: Three Hours **Full Marks: 100**

Answer any five (5) questions

1. a) Define Biot number and Fourier number and state their physical significance.
   b) What do you mean by 'Critical Thickness of Insulation' over a cylindrical body?
   c) A thin-walled copper tube of radius r_i is used to transport a low-temperature refrigerant and is at a temperature T_i that is less than that of the ambient air at T_∞ around the tube. Is there an optimum thickness associated with the application of insulation to the tube considering heat transfer coefficient 'h' as a function of outer radius r_0 and film temperature $(T_0 + T_\infty)/2$; where T_0 is the temperature of the outermost radius of insulation?
   d) Confirm Steam at $T_{\infty 1}$ = 320°C flows in a cast iron pipe (k = 80 W/m · °C) whose inner and outer diameters are D_1 = 5 cm and D_2 = 5.5 cm, respectively. The pipe is covered with 3-cm-thick glass wool insulation with k = 0.05 W/m·°C. Heat is lost to the surroundings at T_2 = 5°C by natural convection and radiation, with a combined heat transfer coefficient of h_2 = 18 W/m2·°C. Taking the heat transfer coefficient inside the pipe to be h_1 = 60 W/m²·°C, determine the rate of heat loss from the steam per unit length of the pipe. Also, determine the temperature drops across the pipe shell and the insulation. Assume one-dimensional steady heat transfer.

Marks: 2 + 2 +8 + 8 = 20

2. a) What do you mean by black body radiation and state their physical significance?
   b) Define Kirchhoff's law of radiation. How it is connected with the graybody assumption?
   c) What is the view factor? State the physical significance of the view factor between two surfaces.
   d) Develop the expression $dA_1 dF_{dA1-dA2} = dA_2 dF_{dA2-dA1}$ of view factor between two elemental surfaces dA_1 and dA_2 located at a distance of r.
   d) Determine the view factors between the surfaces of two concentric spheres with A_1 and A_2 being the surfaces of the inner and outer spheres.

Marks: 3 + 3 +6 + 8 = 20

3. a) Define the Prandtl number, Reynolds number, and Eckert number. State their physical significance.
   b) What are the three different boundary conditions commonly encountered in heat transfer?
   c) Consider two parallel plates located at a distance of L. The Bottom wall is stationary with temperature T_0; whereas the top wall is moving at a velocity U and the temperature of the plate is T_1. From the energy balance equation for Couette flow, deduce the temperature distribution

$$\frac{T - T_0}{T_1 - T_0} = \frac{y}{L} + \frac{\text{Ec.Pr}}{2}\left(\frac{y}{L}\right)\left(1 - \frac{y}{L}\right)$$

Marks: 4 + 4 + 12 = 20

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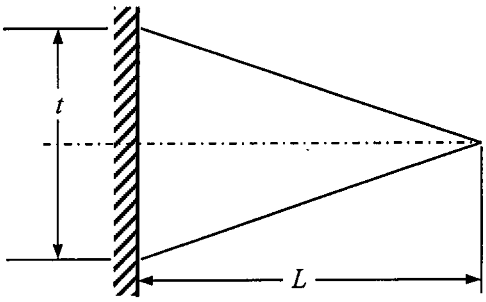
4. a) What do you mean by 'fin'? Describe different types of fins and state their applications in engineering. Also, establish your logic when the application of fin is beneficial and how.

b) Consider a fin having a 'Triangular' profile and it ends up to a point, its dimensions are shown in the figure below. The length of the fin is 'L', the thickness is 't', and the width is 'b'. The fin material has a thermal conductivity k, while the convective heat transfer coefficient at the surface of the fin is h. The fin is attached to a base wall having temperature T_b. From the energy balance across a small element in the fin, develop the governing equation for heat transfer through the fin and write down the boundary conditions.

If a modified Bessel equation in the form of $\frac{d^2y}{dx^2}+\frac{1}{x}\frac{dy}{dx}-y=0$ has a general solution as, $y=C_1I_0(x)+C_2K_0(x)$, where $I_0(x)$ and $K_0(x)$ are the modified zero-order Bessel functions of the first and second kind, respectively, show that the temperature distribution along the fin can be expressed as,

$$\frac{T-T_\infty}{T_b-T_\infty}=\frac{I_0(2B\sqrt{x})}{I_0(2B\sqrt{L})}\text{; assuming } z=2B\sqrt{x}$$



Marks: 5 + 15 = 20

5. a) Consider the flow of a very low Prandtl number (Pr<<1) fluid through a pipe, which is heated with uniform wall heat flux q_w. When the flow is thermally fully developed the energy equation may be expressed as

$$\frac{k}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)=\rho c_p U\frac{\partial T}{\partial x}$$

where, U is the free stream velocity. All the symbols have their usual nomenclature. Find out an expression of bulk fluid temperature T_b in the pipe.

b) The energy equation within the thermal boundary layer above the flat plate can be expressed as $\frac{\partial}{\partial x}\int_0^{\delta_T} u(T-T_\infty)dy=\frac{q_w}{\rho c_p}$

where, q_w is the local wall heat flux on the plate at constant temperature.

Considering Prandtl number Pr<<1 and temperature distribution obtained in (a) above, find an expression for local Nusselt number (Nu) following the integral approach solution.

Marks: 6 + 14 = 20

6. a) Define Fick's law of mass diffusion.

b) Show that for a binary mixture of species A and B, $D_{AB}=D_{BA}$.

c) What is pool boiling? State the physical significance using the boiling curve.