BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)
SECOND YEAR FIRST SEMESTER SUPPLEMENTARY EXAM 2024

HEAT TRANSFER

Time: Three hours Full marks: 100

Answer any *five* questions.
All questions carry equal marks.
Assume any unfurnished data relevant to the solutions.

1. (a) What is lumped system analysis and when is it applicable?

(b) Consider a hot metal body having a volume V, surface area A, density ρ, specific heat c that is initially at a uniform temperature T_i and is suddenly cooled by immersing it in a liquid reservoir at temperature T_a. h is the heat transfer coefficient of convection from the body to the cooling bath. Treating the body as a lumped system, derive an expression for the temperature transient.

(c) Consider a 1.0 m high and 1.5 m wide triple pane window consisting of three 3 mm thick layers of glass (k = 0.78 W/m.^{0}C) separated by two 5 mm wide stagnant air spaces (k = 0.026 W/m.^{0}C) in between the glass panes. Determine the steady rate of heat transfer through the triple pane window for a day during which the room temperature is maintained at 25 ^{0}C while the temperature of the outdoors is -10 ^{0}C. Take the heat transfer coefficients on the inner and the outer surfaces of the window to be 12 W/m^2.^{0}C and 30 W/m^2.^{0}C, respectively.

(3+5+12)

2. (a) What is fin effectiveness? A person claims that he has designed a fin for which the effectiveness is 1.5. Make your comments on the possibility and suitability for use of such a fin.

(b) Consider a straight fin of length L, cross sectional area A and perimeter P with its base maintained at a temperature T_b. The fin loses heat by convection to an ambient at a temperature T_a with heat transfer coefficient h. The thermal conductivity of the fin material is k.

Derive the differential equation that governs the temperature distribution in the fin stating the assumptions. Hence solve for the temperature distribution in the fin, considering it to be infinitely long. Also find the rate of heat flow through the fin and the effectiveness and efficiency of the fin. **(3+17)**

3. Consider Couette flow between two large parallel plates, where, the lower plate is moving with a velocity U_L. The temperatures of the upper and lower plates are T_L and T_0 respectively (T_L > T_0). Obtain the velocity and temperature distributions for the flow, considering zero pressure gradient in the axial direction. The plates are separated by a distance L. **(20)**

[Turn over

4. Consider steady, laminar boundary type flow of a low Prandtl number (Pr<<1) fluid over a flat plate. The free stream velocity and temperature are U_∞ and T_∞ respectively. The plate is maintained at a uniform temperature of T_w. Show the following by the method of scale analysis:

$$\delta / L \sim Re_L^{-1/2}$$

$$\delta_T / L \sim Re_L^{-1/2}\,\mathrm{Pr}^{-1/2}$$

$$Nu_L \sim Re_L^{1/2}\,\mathrm{Pr}^{1/2}$$

(20)

5. (a) Define spectral intensity and directional spectral emissive power of a black body.

(b) Define transmissivity, absorptivity and reflectivity and state how they are related.

(c) Define shape factor. What is reciprocity relation in this connection? **(6+8+6)**

6. (a) Derive the expression for LMTD of a counterflow heat exchanger.

(b) A concentric tube counter flow heat exchanger is used to cool lubricating oil in a steam power plant. The flow rate of cooling water through the inner tube is 0.3 kg/s and its specific heat is 4180 J/kgK. The flow rate of the lubricating oil through the outer annulus is 0.15 kg/s and the specific heat of the lubricating is 2131 J/kgK. The hot oil enters the heat exchanger at 90 ^{0}C and leaves at 50 ^{0}C. The inlet temperature of the cooling water is 20 ^{0}C. The overall heat transfer coefficient is 200 W/m^{2}K. Find the area of heat transfer for the heat exchanger. **(12+8)**

7. (a) Define effectiveness for a heat exchanger.

(b) Show that for a parallel flow heat exchanger, effectiveness is given by

$$\varepsilon = \frac{1-\exp[-NTU(1+C_r)]}{1+C_r}$$

(c) What is the expression for effectiveness when one of the two fluids undergo phase change? **(3+14+3)**