Ex/ME/5/T/211/2024

Bachelor of Engineering (Mechanical Engineering) Second Year First Semester 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 the function of a fin? What is effectiveness of a fin? When is the use of a fin effective?

   (b) Consider a straight fin of length L, having a uniform cross sectional area A and perimeter P. The fin base is maintained at a temperature T_b. The fin loses heat by convection to an ambient at a temperature T_a with a uniform 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 a long one. **(6+14)**

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

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

   (b) Consider steady one dimensional heat conduction across the thickness (L) of a large rectangular plane wall (height=H, width=W) with uniform volumetric heat generation (q_{gen}). The opposite sides across the thickness are maintained at temperatures T_1 and T_2. The thermal conductivity of the wall is k. Starting from appropriate governing equations and boundary conditions, solve for the temperature distrution within the slab. **(8+12)**

3. Consider Couette flow between two parallel plates, where, the upper plate is moving with a velocity U. The temperatures of the upper and lower plates are T_H and T_0 respectively ($T_H > T_0$). The plates are separated by a distance H. Starting from appropriate governing equations and boundary conditions, obtain the velocity and temperature distributions for the flow, considering zero pressure gradient in the axial direction. **(20)**

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 $U\infty$ and $T\infty$ respectively. The plate is maintained at a uniform temperature of Tw. Show the following by the method of scale analysis:

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

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

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

(20)

5. (a) Define spectral intensity and directional spectral emissive power of a black body. Derive the relation between them.

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

(c) What is shape factor? What is reciprocity relation in this connection? **(8+7+5)**

6. (a) Define effectiveness and NTU for a heat exchanger.

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

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

What is the expression for effectiveness when either of the fluids undergo phase change? **(5+15)**

7. (a) Show how tempeartures of the two fluids change along the length of flow in a counter flow heat exchanger? Derive the expression for LMTD of a counterflow heat exchanger.

(b) A double-pipe counter-flow heat exchanger is to cool ethylene glycol (Cp 2560 J/kg °C) flowing at a rate of 3.5 kg/s from 80°C to 40°C by water (Cp 4180 J/kg °C) that enters at 20°C and leaves at 55°C. The overall heat transfer coefficient based on the inner surface area of the tube is 250 W/m^2 °C. Determine (a) the rate of heat transfer, (b) the mass flow rate of water, and (c) the heat transfer surface area on the inner side of the tube. **(10+10)**