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**Question Paper Code : 70908**

B.E./ B.Tech DEGREE EXAMINATIONS, NOVEMBER/DECEMBER 2023.

Sixth/Eighth Semester

Mechanical Engineering

ME 8693 — HEAT AND MASS TRANSFER

(Common to : Mechanical Engineering (Sandwich))

(Regulations 2017)

Time : Three hours

Maximum : 100 marks

Use of Standard Heat and Mass Transfer data book is permitted.

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What is the difference between fin effectiveness and fin efficiency?
2. In what medium is the lumped system analysis more likely to be applicable: in water or in air? Why?
3. Define the Prandtl number. How does Prandtl number help to determine the relationship between thermal boundary layer thickness and hydraulic boundary layer thickness?
4. What is forced convection? How does it differ from natural convection?
5. What is the difference between pool boiling and flow boiling?
6. How does a crossflow heat exchanger differ from a counterflow one?
7. Define the total and spectral blackbody emissive powers. How are they related to each other? How do they differ?
8. How does radiosity for a surface differ from the emitted energy? For what kind of surfaces are these two quantities identical?
9. Give examples for
  - (a) liquid-to-gas,
  - (b) solid-to-liquid mass transfer.
10. What is an impermeable surface in mass transfer? How is it expressed mathematically (on a mass basis)?

PART B — (5 × 13 = 65 marks)

11. (a) A house has a composite wall of wood, fiberglass insulation, and plaster board, as indicated in the figure 1. On a cold winter day, the convection heat transfer coefficients are  $h_o = 60 \text{ W/m}^2 \text{ K}$  and  $h_i = 30 \text{ W/m}^2 \text{ K}$ . The total wall surface area is  $350 \text{ m}^2$ .

- (i) Thermal conductivity of plaster board  $K_p = 0.17 \text{ W/m.K}$   
 (ii) Fiber glass insulation  $K_b = 0.038 \text{ W/m.K}$   
 (iii) Plywood siding  $K_s = 0.12 \text{ W/m.K}$

- (1) Determine a symbolic expression for the total thermal resistance of the wall, including inside and outside convection effects for the prescribed conditions.  
 (2) Determine the total rate of heat loss through the wall.  
 (3) If the wind were blowing violently, raising  $h_o$  to  $300 \text{ W/m}^2 \text{ K}$ , determine the percentage increase in the rate of heat loss.  
 (4) What is the controlling resistance that determines the amount of heat flow through the wall? (4+3+3+3=13)

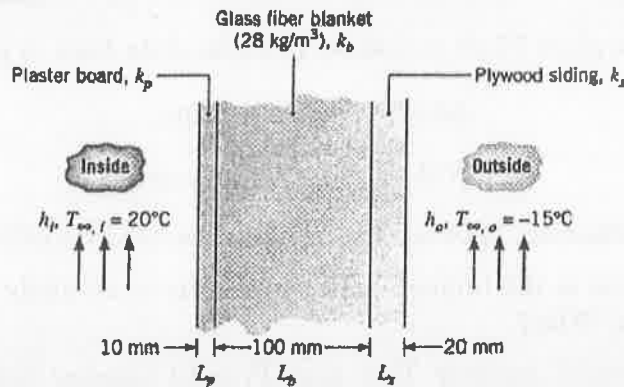


Figure 1.

Or

- (b) (i) What is lumped system analysis? When is it applicable? (3)  
 (ii) Metal cube ( $k = 180 \text{ W/m}\cdot\text{K}$ ,  $\rho = 2800 \text{ kg/m}^3$ , and  $C_p = 880 \text{ J/kg}\cdot\text{K}$ ) with a dimension of  $10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}$  are being cooled by Air at  $20^\circ\text{C}$  with a convection heat transfer coefficient of  $200 \text{ W/m}^2\cdot\text{K}$ . The initial temperature of the plates is  $800^\circ\text{C}$ . Determine the Biot number. Derive the expression for the temperature of the cube after  $t$  sec. Determine the temperature of the cube after 2 min. (2+4+2=8)  
 (iii) From a heat transfer point of view, what is the difference between isotropic and anisotropic materials? (2)

12. (a) (i) What is the physical significance of the Nusselt number? How is it defined? (3)
- (ii) The temperature distribution within a laminar thermal boundary layer associated with flow over an isothermal flat plate is shown in Figure 2. The temperature distribution shown is located at  $x = x_2$ .

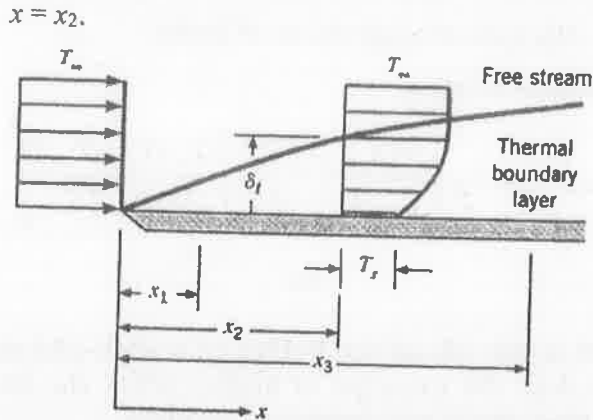


Figure 2.

Is the plate being heated or cooled by the fluid? Carefully sketch the temperature distributions at  $x = x_1$  and  $x = x_3$ . Based on your sketch, at which of the three  $x$  - locations is the local heat flux largest? At which location is the local heat flux smallest? (2+4)

- (iii) For laminar flow over a flat plate, the local heat transfer coefficient  $hx$  is known to vary as  $x^{-1/2}$  where  $x$  is the distance from the leading edge ( $x = 0$ ) of the plate. What is the ratio of the average coefficient between the leading edge and some location  $x$  on the plate to the local coefficient at  $x$ ? (4)

Or

- (b) (i) What is the physical significance of the Nusselt number? How is it defined? (3)
- (ii) Water is to be heated from  $15^\circ\text{C}$  to  $65^\circ\text{C}$  as it flows through a 3-cm-internal diameter 5-m-long tube. The tube is equipped with an electric resistance heater that provides uniform heating throughout the surface of the tube. The outer surface of the heater is well insulated, so that in steady operation all the heat generated in the heater is transferred to the water in the tube. If the system is to provide hot water at a rate of 10 L/min, determine the power rating of the resistance heater. Also, estimate the inner surface temperature of the pipe at the exit. (10)

You can consider the flow in the pipe is fully developed.

13. (a) (i) Discuss different flow regime of flow boiling in a tube. (4)
- (ii) Draw the pool boiling curve and show different boiling regimes. (4)
- (iii) Water is to be boiled at atmospheric pressure in a mechanically polished stainless steel pan placed on top of a heating unit. The inner surface of the bottom of the pan is maintained at 108°C. If the diameter of the bottom of the pan is 30 cm, determine
- (1) the rate of heat transfer to the water and
- (2) the rate of evaporation of water. (5)

Rohsenow relation

$$\dot{q}_{nucleate} = \mu_l h_{fg} \left[ \frac{g(\rho_l - \rho_v)}{\sigma} \right]^{1/2} \left[ \frac{C_{pl}(T_s - T_{sat})}{C_{sf} h_{fg} Pr_l^n} \right]^3$$

Or

- (b) (i) What is the role of the baffles in a shell-and-tube heat exchanger? How does the presence of baffles affect the heat transfer and the pumping power requirements? Explain. (3)
- (ii) What are the common causes of fouling in a heat exchanger? How does fouling affect heat transfer and pressure drop? (3)
- (iii) A long thin-walled double-pipe heat exchanger with tube and shell diameters of 1.0 cm and 2.5 cm, respectively, is used to condense refrigerant 134a by water at 20°C. The refrigerant flows through the tube, with a convection heat transfer coefficient of  $h_i = 5000 \text{ W/m}^2 \cdot \text{°C}$ . Water flows through the shell at a rate of 0.3 kg/s. Determine the Reynolds Number, Nusselt Number and overall heat transfer coefficient of this heat exchanger. (7)
14. (a) (i) What is a graybody? How does it differ from a blackbody? What is a diffuse gray surface? (2+2+3)
- (ii) A horizontal semitransparent plate is uniformly irradiated from above and below, while air at  $T_\infty = 310 \text{ K}$  flows over the top and bottom surfaces, providing a uniform convection heat transfer coefficient of  $h = 50 \text{ W/m}^2 \cdot \text{K}$ . The absorptivity of the plate to the irradiation is 0.40. Under steady state conditions measurements made with a radiation detector above the top surface indicate a radiosity of  $J = 5500 \text{ W/m}^2$ , while the plate is at a uniform temperature of  $T = 360 \text{ K}$ .
- Determine the irradiation  $G$  and the emissivity ( $\epsilon$ ) of the plate.
- Is the plate diffuse-gray ( $\epsilon = \alpha$ ) for the prescribed conditions? (2+2+2)

Or

- (b) (i) Consider a hemispherical furnace with a flat circular base of diameter  $D$  (refer figure 3). Determine the view factor from the dome of this furnace to its base. (3)
- (ii) A flat-bottomed hole 8 mm in diameter is bored to a depth of 24 mm in a diffuse, gray material having an emissivity of 0.8 and a uniform temperature of 1000 K.

ASSUMPTIONS:

- (1) Hypothetical surface  $A_2$  is a blackbody at 0 K,
- (2) Cavity surface is isothermal, opaque and diffuse - gray with uniform radiosity and irradiation distributions. (4+4+2)
- (A) Determine the radiant power leaving the opening of the cavity ( $q_1$ ).
- (B) The effective emissivity  $\epsilon_e$  of a cavity is defined as the ratio of the radiant power leaving the cavity to that from a blackbody having the area of the cavity opening and a temperature of the inner surfaces of the cavity. Calculate the effective emissivity of the cavity described above.
- (C) If the depth of the hole were increased, would  $\epsilon_e$  increase or decrease? What is the limit of  $\epsilon_e$  as the depth increases?

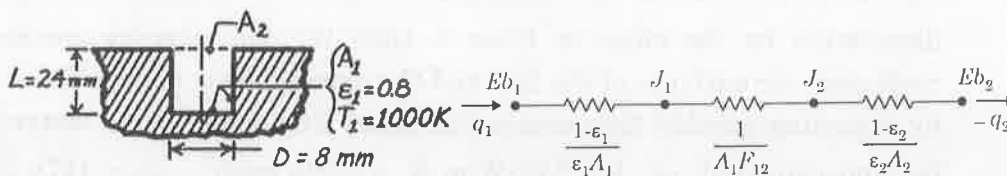


Figure 3.

15. (a) (i) What is the physical significance of the Schmidt number? How is it defined? To what dimensionless number does it correspond in heat transfer? (2+1+1)
- (ii) Dry air at 25°C and atmospheric pressure flows inside a 5-cm-diameter pipe at a velocity of 3m/s. The wall is coated with a thin film of water, and the wall temperature is 25°C. Calculate the water-vapor concentration in the air at exit of a 3-m length of the pipe. (7)
- (iii) What is a concentration boundary layer? How is it defined for flow over a plate? (2)

Or

- (b) (i) What is permeability? How is the permeability of a gas in a solid related to the solubility of the gas in that solid? (3)
- (ii) Determine the mole fraction of dry air at the surface of a lake whose temperature is  $15^\circ\text{C}$ . Take the atmospheric pressure at lake level to be 100 kPa. (4)
- (iii) Write three boundary conditions for mass transfer (on a mass basis) for species A at  $x = 0$  that correspond to specified temperature, specified heat flux, and convection boundary conditions in heat transfer. (3)
- (iv) A wall made of natural rubber separates  $\text{O}_2$  and  $\text{N}_2$  gases at  $25^\circ\text{C}$  and 750 kPa. Determine molar concentrations of  $\text{O}_2$  and  $\text{N}_2$  in the wall. (3)

PART C — (1 × 15 = 15 marks)

16. (a) An array of electronic chips as shown in figure 4, is mounted within a sealed rectangular enclosure, and cooling is implemented by attaching an aluminum heat sink ( $k = 180 \text{ W/m}\cdot\text{K}$ ). The base of the heat sink has dimensions of  $w_1 = w_2 = 100 \text{ mm}$ , while the 6 fins are of thickness  $t = 10 \text{ mm}$  and pitch  $S = 18 \text{ mm}$ . The fin length is  $L_f = 50 \text{ mm}$ , and the base of the heat sink has a thickness of  $L_b = 10 \text{ mm}$ . If cooling is implemented by water flow through the heat sink, with  $u_\infty = 3 \text{ m/s}$  and  $T_\infty = 17^\circ\text{C}$ , what is the base temperature  $T_b$  of the heat sink when power dissipation by the chips is  $P_{\text{elec}} = 1800 \text{ W}$ ? The average convection coefficient for surfaces of the fins and the exposed base may be estimated by assuming parallel flow over a flat plate. Properties of the water may be approximated as  $k = 0.62 \text{ W/m}\cdot\text{K}$ ,  $\rho = 995 \text{ kg/m}^3$ ,  $c_p = 4178 \text{ J/kg}$ ,  $\nu = 7.73 \times 10^{-7} \text{ m}^2/\text{s}$ , and  $\text{Pr} = 5.2$ .

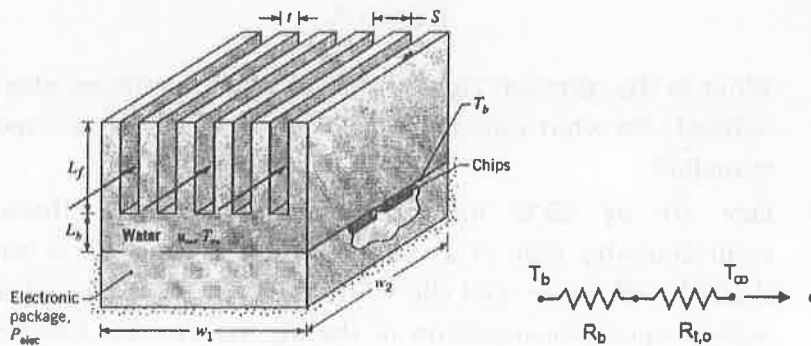


Figure 4

Or

(b) A concentric tube heat exchanger for cooling lubricating oil consists of a thin-walled inner tube shown in Figure 5, of 25-mm diameter carrying water and an outer tube of 45-mm diameter carrying the oil. The exchanger operates in counterflow with an overall heat transfer coefficient of  $55 \text{ W/m}^2\cdot\text{K}$  and the tabulated average properties.

- (i) If the outlet temperature of the oil is  $50^\circ\text{C}$ , determine the total rate of heat transfer and the outlet temperature of the water.
- (ii) Determine the length required for the heat exchanger.

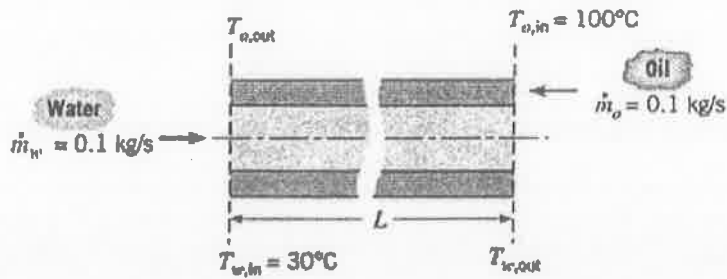


Figure 5

Properties	Water	Oil
$\rho \text{ (kg/m}^3\text{)}$	1000	800
$c_p \text{ (J/kg} \cdot \text{K)}$	4200	1900
$\nu \text{ (m}^2\text{/s)}$	$7 \times 10^{-7}$	$1 \times 10^{-5}$
$k \text{ (W/m} \cdot \text{K)}$	0.64	0.134
$Pr$	4.7	140