Reg. No. :

Question Paper Code : 40840

B.E./B.Tech. DEGREE EXAMINATIONS, NOVEMBER/DECEMBER 2021.

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 thermodynamic Property table is permitted.

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. What is the physical significance of thermal diffusivity? What is the SI unit of thermal diffusivity?

2. Arrange the following materials from lowest to highest thermal conductivity

   Copper, water, mercury, hydrogen, steel, diamond

3. Draw the thermal and hydrodynamic boundary layer over a flat plate for Prandtl number less than one.

4. In free or natural convection, which non-dimensional number determines the transition from laminar to turbulent? What is the relationship of the that non-dimensional number with Grashof and Prandtl number?

5. What is Nusselt number and what is its dimension in SI unit?

6. What are the different types of heat exchange?

7. What is the relationship between transmittivity, reflectivity and absorptivity for a general transparent body and an opaque body?

8. What is the use of radiation shields?

9. Define Fick's law of diffusion.

10. Compare between heat transfer and mass transfer.

PART B — (5 × 13 = 65 marks)

11. (a) The temperature distribution across a wall 0.3 m thick after attaining steady state is $T(x) = a + bx + cx^2$, where T is in degrees Celsius and x is in meters, The wall has a thermal conductivity of 1 W/m–K. (2 + 3 + 5 + 3 = 13)

(i) Write down the governing differential equation for the heat transfer in the wall.

(ii) Write down the units of a, b and c.

(iii) The numerical value of a, b and c are 200, –200, 30 respectively. On a unit surface area basis, determine the rate of heat transfer into and out of the wall and the rate of change of energy stored by the wall.

Or

(b) Consider a round potato (spherical) being baked in an oven. Would you model the heat transfer to the potato as one-, two-, or three-dimensional? Would the heat transfer be steady or transient? Also, which coordinate system (Cartesian. cylindrical or spherical) would you use to solve this problem, and where would you place the origin? Explain. (13)

12. (a) The top surface of the passenger car of a train moving at a velocity of 70 km/h is 2.8 m wide and 8 m long. The top surface is absorbing solar radiation at a rate of 200 W/m², and the temperature of the ambient air is 30°C. Assuming the roof of the car to be perfectly insulated and the radiation heat exchange with the surroundings to be small relative to convection, determine the equilibrium temperature of the top surface of the car. The properties of air at 30°C are : k = 0.02588 W/m°C, $\upsilon = 1.608 \times 10^{-5}$ m²/s, Pr = 0.7282. The average Nusselt number relations for flow over a flat plate are :

Laminar : $Nu = \dfrac{hL}{k} = 0.664\ \mathrm{Re}_L^{0.5}\ \mathrm{Pr}^{1/3}$ $\quad \mathrm{Re}_L < 5\times10^5$

Turbulent : $Nu = \dfrac{hL}{k} = 0.037\ \mathrm{Re}_L^{0.8}\ \mathrm{Pr}^{1/3}$ $\quad 0.6 \le \mathrm{Pr} \le 60$, $5\times10^5 \le \mathrm{Re}_L \le 10^7$

Combined : $Nu = \dfrac{hL}{k} = \left(0.037\,\mathrm{Re}_L^{0.8} - 871\right)\mathrm{Pr}^{1/3}$, $\quad 0.6 \le \mathrm{Pr} \le 60$, $5\times10^5 \le \mathrm{Re}_L \le 10^7$ (13)

Or

(b) Hot water at 90°C enters a 15-m section of a cast iron pipe (k = 52 W/m–°C) whose inner and outer diameters are 4 and 4.6 cm, respectively, at an average velocity of 0.8 m/s. The outer surface of the pipe, whose emissivity is 0.7, is exposed to the cold air at 10°C, with a convection heat transfer coefficient of 15 W/m^2–°C. The walls of the room are at 10°C. The properties of water at 90°C are – ρ = 965.3 kg/m^3, k = 0.675 W/m-K, υ = 0.326 × 10^{-6} m^2/s, Cp = 4206 J/kg–K, Pr = 1.96. Friction factor = 0.0065, $Nu = 0.125\, fRePr^{1/3}$. Assume fully developed flow through out the pipe and neglect the conduction resistance of the pipe. determine (i) The mass flow rate of water through the pipe, (ii) Reynolds Numb , (iii) Nusselt Number, (iv) convective heat transfer coefficient inside the pipe, (v) the rate of heat loss from the water and (vi) the temperature at which the water leaves the basement. (13)

13. (a) Steam at 40°C condenses on the outside of a 3-cm diameter thin horizontal copper tube by cooling water that enters the tube at 25°C at an average velocity of 2 m/s and leaves at 35°C. Determine the rate of condensation of steam, the average overall heat transfer coefficient between the steam and the cooling water, and the tube length.

Use the following correlations :

For inside a horizontal tube :

$$Nu = 0.023\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.4}$$

For the outside of a horizontal tube with film condensation

$$h_o = h_{horizontal} = 0.729\left[\frac{g\rho_1(\rho_1 - \rho_v)h^*_{fg}\, k_l^3}{\mu_1(T_{sat} - T_s)D}\right]^{1/4} \qquad (13)$$

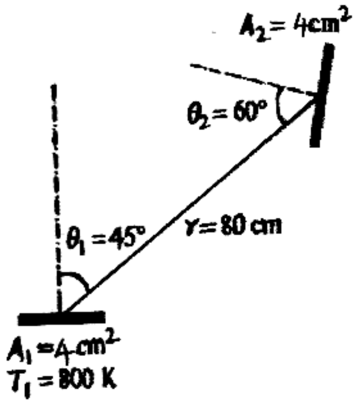
Or

(b) Cold water (Cp = 4180 J/kg °C) leading to a shower enters a thin-walled double-pipe counter-flow heat exchanger at 15°C at a rate of 0.25 kg/s and is heated to 45°C by hot water (Cp = 4190 J/kg.°C) that enters at 100°C at a rate of 3 kg/s. If the overall heat transfer coefficient is 950 W/m2.°C, determine the rate of heat transfer and the heat transfer surface area of the heat exchanger using the ε–NTU method. (13)

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

14. (a) (i) What does the view factor represent? When is the view factor from a surface to itself not zero? (6)

(ii) A small surface of area A_1 = 4 cm^2 emits radiation as a blackbody at T1 = 800 K. Part of the radiation emitted by A1 strikes another small surface of area A_2 = 4 cm^2 oriented as shown in the figure. Determine the solid angle subtended by A_2 when viewed from A_1, and the rate at which radiation emitted by A_1 that strikes A_2 directly. What would your answer be if A_2 were directly above A_1 at a distance of 80 cm? (7)



Or

(b) (i) Define the properties emissivity and absorptivity. When are these two properties equal to each other? (6)

(ii) A 5 m square room has a ceiling maintained at 28°C and a floor maintained at 20°C. The connecting walls are 4 m high and perfectly insulated. Emissivity of the ceiling is 0.62 and that of the floor is 0.75. Calculate the heat transfer from ceiling to floor, and the temperature of the connecting walls. (7)

15. (a) (i) Give examples for (1) liquid-to-gas (2) solid-to-liquid, (3) solid-to-gas and (4) gas-to-liquid mass transfer. (6)

(ii) Helium gas is stored at 293 K in a 3 m outer diameter spherical container made of 5 cm thick Pyrex. The molar concentration of helium in the Pyrex is 0.00073 kmol/m^3 at the inner surface and negligible at the outer surface. Determine the mass flow rate of helium by diffusion through the Pyrex container. (7)

Or

(b) Consider a 15 cm internal diameter, 10 m long circular duct whose interior surface is wet. The duet is to be dried by forcing dry air at 1 atm and 15°C through it at an average velocity of 3 m/s. The duct passes through a chilled room, and it remains at an average temperature of i5°C at all times. For low mass flux conditions, we can use dry air properties can be used (υ = 1.702 × 10^{-5} m^2/s). Determine

(i) The mass diffusivity of water vapor in air at 313 K

$$D_{H_2O-Air} = 1.87 \times 10^{-10} \frac{T^{2.072}}{P} (m^2/s), \; 280 \text{ K} < T < 450 \text{ K}$$

(ii) The Reynolds number

(iii) The Schmidt number

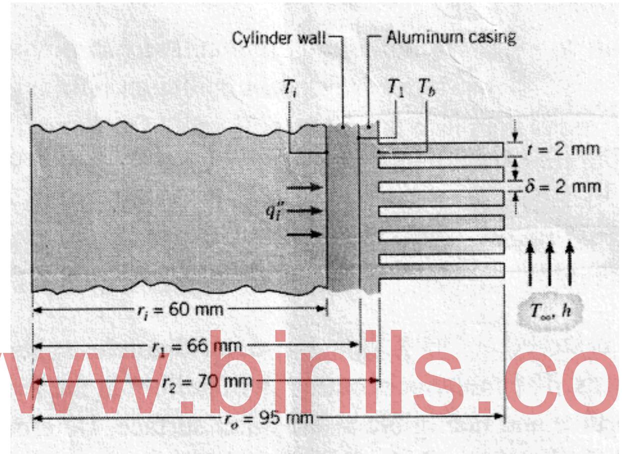
(iv) The Sherwood number

$$Sh = \left(0.037\,Re^{0.8} - 871\right)Sc^{1/3}$$

(v) The mass transfer coefficient in the duct. (13)

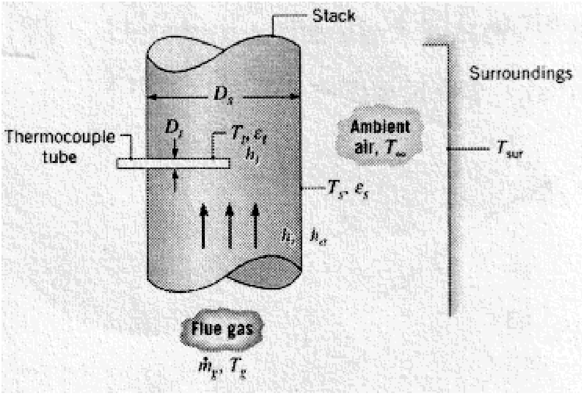
PART C — (1 × 15 = 15 marks)

16. (a) It is proposed to air-cool the cylinders of a combustion chamber by joining an aluminum casing with annular fins (k = 240 W/m – K) to the cylinder wail (k = 50 W/m – K). The air is at 320 K and the corresponding convection coefficient is 100 W/m2 - K. Although heating at the inner surface is periodic, it is reasonable to assume steady-state conditions with a time-averaged heat flux of $q'' = 10^5$ W/m2. Determine the wall inner temperature T_i, the interface temperature T1, and the fin base temperature T_b. The interface contact resistance is $R''_{t,c} = 10^{-4}$ m²-K/W.



Or

(b) The temperature of flue gases flowing through the large stack of a boiler is measured by means of a thermocouple enclosed within a cylindrical tube as shown. The tube axis is oriented normal to the gas flow, and the thermocouple senses a temperature T_t corresponding to that of the tube surface. The gas flow rate and temperature are designated $\dot{m}_g$ and T_g, respectively, and the gas flow may be assumed to be fully developed. The stack is fabricated from sheet metal that is at a uniform temperature Ts and is exposed to ambient air at T_∞. and large surroundings at T_{sur}. The convection coefficient associated with the outer surface of the duct is designated as ho, while those associated with the inner surface of the duct and the tube surface are designated as hi and ht, respectively. The tube and duct surface emissivities are designated as ε_t and ε_s, respectively.



Zukauskus correlation (for thermocouple tube surface) :

$$\overline{Nu}_D = 0.26\,Re_{Dt}^{0.6} Pr^{0.37}$$

Dittus-Boelter correlation (for inner surface of the tube) :

$$h_i = \frac{k}{D_S} 0.023\,Re_{Ds}^{4/5} Pr^{0.3}$$

(i) Find out Tg as a function of Ts using

(1) energy balance applied to a control surface about the thermocouple

(2) an energy balance on the stack wall

(ii) Predict the thermocouple error (Tg – Tt) in the temperature measurement if Ts is 388K.

Tt = 300°C, Ds = 0.6 m, Dt = 10 mm, $M_g = 1$ kg/s, $T_\infty = T_{surr} = 27^\circ C$, $\varepsilon_t = \varepsilon_s = 0.8$ and $ho = 25$ W/m^2 – K.

Air (Tg ≈ 600 K, pg = 1 atm) : $\rho = 0.58$ kg/m^3;

$\mu = 305.8 \times 10^{-7}$ N.s/m^2, $\upsilon = 52.7 \times 10^{-6}$ m^2/s, k = 0.0469 W/m.K,

Pr = 0.685.

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