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APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

B.Tech Degree S6 (S, FE) / S4 (PT) (S, FE) Examination January 2024 (2015 Scheme)

Course Code: ME302

Course Name: Heat and Mass Transfer

Use of heat and mass transfer data book permitted

Max. Marks: 100 Duration: 3 Hours

PART A

Answer any three full questions, each carries 10 marks. Marks

1 a) What is the physical significance of the thermal diffusivity? How is it defined and what is its unit? (3)

b) The steady-state temperature distribution in a one-dimensional wall of thermal conductivity 50W/mK and thickness 50 mm is observed to be T(C)= $a+bx^2$, where a= 200 °C, b= -2000 °C/m^2, and x is in meters. What is the heat generation rate in the wall? Also determine the heat fluxes at the two wall faces. (7)

2 a) The walls of a refrigerator are typically constructed by sandwiching a layer of insulation between sheet metal panels. Consider a wall made from fiberglass insulation of thermal conductivity k_i =0.046 W/mK and thickness L_i= 50 mm and steel panels, each of thermal conductivity k_p =60 W/mK and thickness L_p=3 mm. If the wall separates refrigerated air at $T_{\infty,i}$ =4 °C from ambient air at $T_{\infty,o}$ =25 °C, what is the heat gain per unit surface area? Coefficients associated with natural convection at the inner and outer surfaces may be approximated as h_i=h_o=5 W/m^{2}K. (7)

b) What is the physical basis for existence of a critical insulation radius? How do the thermal conductivity and the convection coefficient affect its value? (3)

3 a) What is the definition of the Prandtl number? How does its value affect relative growth of the velocity and thermal boundary layers for laminar flow over a surface? (3)

b) A long 8-cm-diameter steam pipe whose external surface temperature is 90°C passes through some open area that is not protected against the winds. (7)

Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 7°C and the wind is blowing across the pipe at a velocity of 50 km/h.

4 a) For a hot horizontal plate in quiescent air, do you expect heat transfer to be larger for the top or bottom surface? Why? (3)

b) Consider a vertical plate of dimension 0.25 m×0.50 m that is at T_s=100 °C in a quiescent environment at T_∞= 20°C. In the interest of minimizing heat transfer from the plate, which orientation, (A – the 0.25m side kept vertical) or (B – the 0.5m side kept vertical), is preferred? What is the convection heat transfer from the front surface of the plate when it is in the preferred orientation? (7)

PART B

Answer any three full questions, each carries 10 marks.

5 a) Is the lumped capacitance method of analysis likely to be more applicable for a hot solid being cooled by forced convection in air or in water? Why? (3)

b) Steel balls 12 mm in diameter are annealed by heating to 1150 K and then slowly cooling to 400 K in atmospheric air at T_∞=300 K and h=20 W/m^{2}K. Assuming the properties of the steel to be k=40 W/mK, ρ=7800 kg/m^3, and c= 600 J/kgK, estimate the time required for the cooling process. (7)

6 a) What is the fin effectiveness? Under what conditions are fins most effective? (4)

b) A 40-mm-long, 2-mm-diameter pin fin is fabricated of an aluminum alloy (k=140 W/mK). Determine the fin heat transfer rate for base temperature, T_b=50°C, ambient temperature, T_∞=25°C, and heat transfer coefficient, h= 1000 W/m^{2}K, and an adiabatic tip condition. (6)

7 a) Why is the maximum possible heat rate for a heat exchanger not equal to $C_{max}(T_{h,inlet} - T_{c,inlet})$, where C_{max} is the higher heat capacity among the hot and cold fluids. (4)

b) A two-fluid heat exchanger has inlet and outlet temperatures of 65 °C and 40 °C for the hot fluid and 15 °C and 50 °C for the cold fluid. Can you tell whether this exchanger is operating under counter-flow or parallel flow conditions? Determine the effectiveness of the heat exchanger. (6)

8 A boiler used to generate saturated steam is in the form of an unfinned, cross-flow heat exchanger, with water flowing through the tubes and a high-temperature gas in cross flow over the tubes. The gas, which has a specific heat (10)

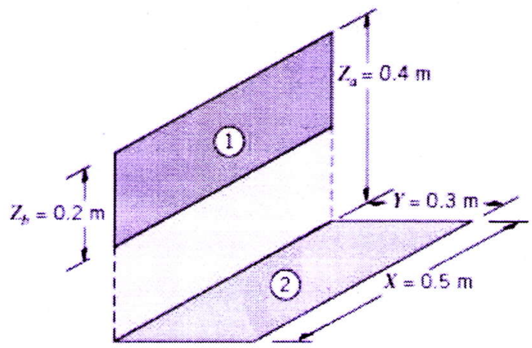
of 1120 J/kg.K and a mass flow rate of 10 kg/s, enters the heat exchanger at 1400 K. The water, which has a flow rate of 3 kg/s, enters as saturated liquid at 450 K and leaves as saturated vapor at the same temperature. If the overall heat transfer coefficient is 50 $W/m^2.K$ and there are 500 tubes, each of 0.025-m diameter, what is the required tube length? (The enthalpy of vaporization of water (at 450K) is, h_{fg}=2024 kJ/kg)

PART C

Answer any four full questions, each carries 10 marks.

9 a) What are the characteristics of a blackbody? Does such a thing actually exist in nature? What is the principal role of blackbody behavior in radiation analysis? (4)

b) Consider the perpendicular rectangles shown schematically. (6)



Determine the shape factor F_{12}.

10 Heat transfer by radiation occurs between two large parallel plates, which are maintained at temperatures T_1 and T_2, with $T_1>T_2$. To reduce the rate of heat transfer between the plates, it is proposed that they be separated by a thin shield that has different emissivities on opposite surfaces. In particular, one surface has the emissivity $\varepsilon_s<0.5$, while the opposite surface has an emissivity of $2\varepsilon_s$. How should the shield be oriented to provide the larger reduction in heat transfer between the plates? That is, should the surface of emissivity ε_s or that of emissivity $2\varepsilon_s$ be oriented toward the plate at T_1? What orientation will result in the larger value of the shield temperature T_s? (10)

11 a) What are the radiation surface and space resistances? How are they expressed? For what kind of surfaces is the radiation surface resistance zero? (3)

b) Two parallel disks of diameter D= 0.6 m separated by L= 0.4 m are located directly on top of each other. Both disks are black and are maintained at a temperature of 700 K. The back sides of the disks are insulated, and the (7) environment that the disks are in can be considered to be a blackbody at T_∞=300 K. Determine the net rate of radiation heat transfer from the disks to the environment.

12 a) State Fick's law of mass diffusion. What is mass diffusivity? What is its dimension? (4)

b) A thin plastic membrane separates hydrogen from air. The molar concentrations of hydrogen in the membrane at the inner and outer surfaces are determined to be 0.065 and 0.003 kmol/m^3, respectively. The binary diffusion coefficient of hydrogen in plastic at the operation temperature is 5.3×10^{-10} m^2/s. Determine the mass flow rate of hydrogen by diffusion through the membrane under steady conditions if the thickness of the membrane is (*a*) 2 mm and (*b*) 0.5 mm. (6)

13 a) Consider two identical cups of coffee, one with no sugar and the other with plenty of sugar at the bottom. Initially, both cups are at the same temperature. If left unattended, which cup of coffee will cool faster? Why? (3)

b) What is the physical significance of the Sherwood number? How is it defined? To what dimensionless number does it correspond in heat transfer? What does a Sherwood number of 1 indicate for a plain fluid layer? (4)

c) What is the relation $(f/2)Re=Nu=Sh$ known as? Under what conditions is it valid? What is the practical importance of it? (f- friction factor, Re – Reynolds number, Nu – Nusselt number, Sh – Sherwood number) (3)

14 a) What is equimolar counter diffusion? Does it have any counterpart in heat transfer? (3)

b) Air at 1atm, 25 °C, containing small quantities of iodine flows with a velocity of 5.18m/s inside a 3.048 cm diameter tube. Determine the mass transfer coefficient for iodine transfer from the gas stream to the wall surface. If C_m is the mean concentration of iodine in kg mol/m^3 in the air stream, determine the rate of deposition of iodine on the tube surface (in terms of C_m) where the iodine concentration is zero. (7)

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