Question Paper

Exam Date & Time: 11-Jun-2022 (02:00 PM - 05:00 PM)

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

IV Semester End Semester Examination

PRINCIPLES OF HEAT & MASS TRANSFER OPERATIONS [BIO 2254]

Marks: 50 **Duration: 180 mins.**

Descriptive Questions

Answer all the questions.

1) A) A certain flat material 200 mm thick with cross sectional area of 0.1m^2 has one side maintained at 35^0C and the other at 95^0C. The temperature at the centre plane of the material is 62^0C and heat flow through the material is 10kW. Determine the values of a and b for thermal conductivity of the material k=a + bT, T in ^{0}C, k in W/m ^{0}C (4)

B) Prove that the radius of critical insulation (r_c) around a pipe is r_c = k/h; where k is the thermal conductivity of the pipe material and h is the heat transfer coefficient (3)

C) Gaseous Oxygen 80^0 C flows inside a 20mm ID pipe at 150kPa and with a mean velocity of 5m/s. Tube wall is at constant temperature of 127^0 C. Compute the average heat transfer coefficient. Average properties of Oxygen: μ (viscosity) = 20μPa.s, k=0.0297W/mK, Cp=1043 J/kgK , R=8314 J/(kmol K), $Nu=0.023Re^{0.8}Pr^{0.3}$ (3)

2) A) Blood passing through a 2.5 mm ID steel tube is to be warmed from 32^0 C to 37.3^0C. The volumetric flow rate is 15 mL/s and the tube wall is heated electrically to provide a uniform flux. It is important to prevent the wall temperature from exceeding 43^0 C to prevent damage to blood. Approximating blood properties to that of water, what is the minimum tube length that is required? ρ=996.2 kg/m^3, Cp=4176 J/kgK, μ/ρ =7.51x$10^{-7}$$m^2$/s, k=0.619 W/mK. (5)

$Nu=2\ Gz^{0.333}$; $Gz= (m'C_p/kL)$

B) Steam at 100^0 C is being condensed on the inside surface of a horizontal tube of 3 m length and 50 mm OD and tube surface is maintained at 80^0 C. Determine the required flow rate of cooling water entering at 30^0 C and leaving at 70^0 C flowing outside the tube. Average properties of water ρ=962 kg/m^3, k=0.677 W/mK, Cp=4179 J/kgK, (3)

μ=-3.0x10^{-4}kg/ms, λ=2.27x10^6J/kg Assume negligible tube thickness

$$\bar{h} = 0.555\left(\frac{\rho^2 k^3 g \lambda}{\mu D \Delta T}\right)^{0.25}$$

C) With q (W/m^2) on y axis and ΔT on x axis explain the various regimes of boiling heat transfer (2)

3) A) Water is heated by a 200mmx200mm vertical flat plate maintained at 60^0 C. Find the rate of heat transfer (kW) when the water is at 20^0 C. At the mean film temperature of 40^0 C, the properties of water; k = 0.628 W/mK, Cp=4180J/kgK, ρ = 994 kg/m^3, μ/ρ = 0.658x10^{-6} m^2/s, for every 100^0C rise in temperature volume increases by 3%. (4)

$Nu = 0.1(GrPr)^{1/3}$; $Gr = L^3\rho^2 g\beta\,(\Delta T)/\mu^2$

B) Explain the following in the context of radiation heat transfer (3)

(i) Gray Body

(ii) Kirchoff's law

(iii) Wein's displacement law

C) Determine the net heat transfer by radiation between two surfaces A1 and A2 expresses as watts per meter square of area A2, if the temperature of A1 and A2 are 500^0 C and 200^0 C respectively and emissivities of A2 and A1 are 0.90 and 0.25 respectively. Both the surfaces are gray. Stefan Boltzmann constant $=5.6\times10^{-8} W/m^2K^4$ (3)

(i) Surface A1 and A2 are infinite parallel planes, 3 m apar

$$F_{12} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

(ii) Surface A2 is a spherical shell 2 m in diameter and surface A1 is a similar shell concentric with A2 and 0.2 m in diameter, A1 is area of the enclosed body and A2 is the area of the enclosure.

$$F_{12} = \frac{1}{\frac{1}{\varepsilon_1} + \left(\frac{A_1}{A_2}\right)\frac{1}{\varepsilon_2} - 1}$$

4) What is HETP? On what factors does the HETP depends? (3)

A)

B) An open circular tank 8m in diameter contains n-Propanol at 25^0C exposed to the atmosphere in such a manner that the liquid is covered with a stagnant air film estimated to be 5mm thick. The concentration of propanol beyond stagnant film is negligible. The vapor pressure of propanol at 25^0C is 20mmHg. If propanol is worth ₹ 320 per litre, what is the value of loss of propanol in Rs per day? The specific gravity of n- Propanol is 0.8. Diffusivity of propanol in air is 0.1329 cm^2/s. Assume non diffusion of air through the film. Mol. wt. of n-Propanol is 60. R=8314J/kmol K (4)

$$NA = \frac{D_{AB} P_t}{RT\ Z\ P_{B,m}} \left(\bar{p}_{A1} - \bar{p}_{A2} \right)$$

C) Starting with fundamentals of diffusion (Fick's Law and using basic concepts of J_A and N_A) using the usual notations, prove that flux of A (N_A) for the counter current diffusion of gases A and B such that $N_B = -3N_A$ is given by (3)

$$N_A = \frac{D_{AB} P_t}{2RTZ}\, ln \left(\frac{0.5 + Y_{A1}}{0.5 + Y_{A2}}\right)$$

5) A) During absorption of CCl_4 from a mixture of air-CCl_4 by an organic oil, the individual gas and liquid phase mass transfer coefficients have been estimated to be 0.32 and 5.26 kmol/[hr. m^2. mol fraction] respectively. At a given location, the mole fractions of CCl_4 is found to be 0.3 and 0.01 in gas and liquid respectively. The equilibrium relationship under operating condition is given by y = 20*x, where x and y are mole fractions of CCl_4 in liquid and gas phases respectively. (4)

i. Estimate overall mass transfer coefficients K_x and K_y in kmol/[hr. m^2. mol fraction]

ii. Estimate the flux of CCl_4 in kmol/(hr. m^2)

iii. Determine interfacial composition

iv. Resistances in the liquid and gas phases

$$\frac{1}{K_x} = \frac{1}{k_x} + \frac{1}{m'' k_y} \qquad \frac{1}{K_y} = \frac{1}{k_y} + \frac{m'}{k_x}$$

B) Mass transfer coefficient of O_2 from a bubble rising in water is calculated using Winnikow equation (1967) at 25^{0}C. (4)

$$\mathrm{Sh} = \frac{2\sqrt{\mathrm{Pe}}}{\sqrt{\pi}} \sqrt{\left(1 - \frac{2.89}{\sqrt{\mathrm{Re}}}\right)}$$

Compute the flux of oxygen from rising air bubbles (g-O_2/m^2.s) based on the concentrations in the bulk and saturation oxygen concentration, Re based on water.

Data: Average bubble diameter =3 mm; Rise velocity = 5cm/s;

Viscosity of water = 8.9x10^{-4}Pa.s; density of water=995 kg/m^3;

Sh=kL/D; Pe=Lu/D; L= characteristic dimension, m, D= diffusivity m^2/s

Diffusivity of oxygen in water =2x10^{-5}cm^2/s; Saturation Oxygen concentration in water = 8 ppm (by wt, g/g), Concentration of oxygen in bulk =4 ppm (by wt, g/g).

Assume that saturation exists at bubble interface.

C) Following is the data of carbon dioxide in polymer polypropylene (PP) (2)

Diffusivity =9.6x10^{-9}m^2/s

Solubility = 0.75 x 10^{-8} [g-gas/(g-PP).atm]

Density of polypropylene = 0.78 g-PP/cm^{3}PP

CO_2 is diffusing through a flat sheet of thickness 3 mm made of PP

Partial pressure of CO_2 on one side = 0.29 atm

Partial pressure of CO_2 on the other side = 0.5 atm

I. Compute the concentrations on both sides (C_{A1} and C_{A2}) in the solid polymer PP in g-gas/cm^3-PP

II. Determine flux of diffusion in g-gas/cm^2.s

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