MANICALAND STATE UNIVERSITY OF APPLIED SCIENCES

FACULTY OF ENGINEERING

Chemical and Processing Engineering Department

TRANSPORT PHENOMENA

CODE: HCHE 212

SESSIONAL EXAMINATIONS
FEBRUARY 2021

DURATION: 3 HOURS

EXAMINER: T. C. NKHOMA

INFORMATION AND INSTRUCTIONS

1. This paper consists of 5 pages
2. Answer **ALL** questions

QUESTION 1

a) To measure the diffusivity of CO_2 by twin bulb method, pure CO_2 and pure N_2 are filled in bulb 1 and bulb 2, respectively. The volume of bulb 1 is $4.5*10^{-3}$ m^3 and bulb 2 is $2.5*10^{-3}$ m^3. These two bulbs are connected by a capillary tube of 8cm length and 2cm internal diameter. The partial pressure of CO_2 in bulb 1 and bulb 2 are 70kPa and 50kPa respectively at the end of 15hrs. The bulbs maintained at 150kPa total pressure and 305 K temperature. Calculate diffusivity of CO_2. [10]

b) Differentiate mass transfer by diffusion and by convection with the aid of an example. [2]

c) Consider two ideal gas species A and B which are diffusing into each other. If the general flux for transport of a species A on the x-direction is given by,

$$N_A = J_A + y_A N$$

(i) Give the meaning of each of the terms in the general flux expression [4]

(ii) What is the physical significance of J_A [2]

d) A feed gas consisting of methane, ethane, normal propane and butane is fed to an absorber at 330 K and 150 kPa as shown in Fig 1 below. For a basis of 100 kmol, calculate the:

(i) Composition of the feed gas in terms of mass fraction and [6]

(ii) Total mass concentration of the feed gas [4]

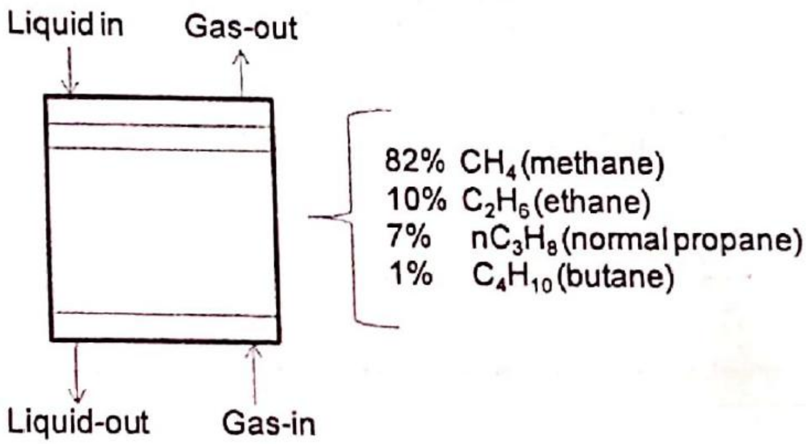

Fig 1

e) Give two industrial applications of diffusion in solids [2]

QUESTION 2

a) A test tube, 1.5 cm in diameter and 18 cm long, has 0.4 g camphor ($C_{10}H_{16}O$) in it. How long will it take for camphor to disappear? The pressure is atmospheric and temperature is 20^0C. The sublimation pressure of camphor at this temperature is 97.5 mm Hg; diffusivity of camphor can be estimated by using Fuller's Equation: $D_{AB} = \frac{1.0133*10^{-7}T^{1.75}}{P\left[(\sum v_A)^{1/3}+(\sum v_B)^{1/3}\right]^2}\left[\frac{1}{M_A}+\frac{1}{M_B}\right]^{1/2}$ m^2/s

Where, T in K;

P in bar,

M_A, M_B are molecular weights of A and B, respectively.

$\sum v_A = 202.16\frac{m}{s}$; $\sum v_B = 20.1\ m/s$ [15]

b) Discuss the importance and application of Navier-Stokes equations in Transport Phenomena [5]

QUESTION 3

a) Compare and contrast heat transfer by conduction with heat transfer by convection. [2]

b) The wall of an oven consists of three layers of brick. The inside is built of 8 in of firebrick, k = 0.68 Btu/hr.ft.^{o}F , surrounded by 5 in of insulating brick, k = 0.15 Btu/hr.ft.^{o}F and an outer layer of 7 in of the building brick, k = 0.40 Btu/hr.ft.^{o}F. The oven operates at 1600 ^{o}F and it is anticipated that the outer side of the wall can be maintained at 125 ^{o}F by circulation of air. How much heat will be lost per unit area and what are the temperatures at the interface of the layers. [15]

c) Define the Nusselt number and give its physical significance [2]

d) Classify heat exchangers according to flow type and explain the characteristic of each type [6]

QUESTION 4

a) Differentiate radiation from the other two forms of heat transfer [2]

b) Air enters a 20 cm diameter 12 cm long underwater duct at 50 ^{o}C and 1 atm at a mean velocity of 7m/s, and is cooled by the water outside. If the average heat transfer coefficient is 85 W/m^{2o}C and the tube temperature is nearly equal to the water temperature of 5 ^{o}C, determine the exit temperature of air and the rate of heat transfer [10]

c) Explain the physical significance of the diffusion coefficient of A into B, D_{AB} [3]

d) For diffusivity measurement using a diaphragm cell method,

(i) Discuss the experiment process include diagrams and assumptions [8]

(ii) Identify the species phase in which they are used [2]

Formulae and Constants

Atomic weights (H = 1, C = 12, O = 16, N = 14): Atomic volumes (C = 16.5, O = 5.48, H = 2.31)

$$J_A = -D_{AB}\left(\frac{dC_A}{dx}\right) \qquad N_A = J_A + \frac{C_A}{C}N$$

$$\frac{\partial C_A}{\partial t} = D_{AB}\left(\frac{\partial^2 C_A}{\partial x^2} + \frac{\partial^2 C_A}{\partial y} + \frac{\partial^2 C_A}{\partial z^2}\right) \qquad N_A = \frac{D_{AB}}{RT(x_2-x_1)}\frac{P_t}{P_{BLM}}(P_{A1} - P_{A2}) \qquad P_{BLM} = \frac{P_{B2}-P_{B1}}{\ln\left(\frac{P_{B2}}{P_{B1}}\right)}$$

$$N_A = \frac{D_{AB}P_t}{RT(x_2-x_1)}(P_{A1} - P_{A2}) \qquad \widehat{N}_A = \frac{\sqrt{3}D_{AB}P_t}{4RT}\left(\frac{a_1 a_2}{x_2-x_1}\right)\ln\left(\frac{P_t-P_{A1}}{P_t-P_{A2}}\right),$$

$$\widehat{N}_A = \frac{D_{AB}\pi}{RT}\left(\frac{r_1 r_2}{L}\right)(P_{A1} - P_{A2}), \qquad N_A = D_{AB}\left(\frac{C_{A,1}-C_{A,2}}{L}\right)$$

$$ln\left(\frac{P_t}{P_{A1,t}-P_{A2,t}}\right) = \frac{A_x D_{AB}}{L}\left(\frac{1}{V_1}+\frac{1}{V_2}\right)t, \qquad D_{AB} = \frac{RT P_{BLM}(H_f^2 - H_0^2)}{2P_t M_A (P_{A1}-P_{A2})t_f},$$

$$D_{AB} = \frac{10^{-7}T^{1.75}}{P_t\left[(\sum V_A)^{\frac{1}{3}}+(\sum V_B)^{\frac{1}{3}}\right]^2}\left(\sqrt{\frac{1}{M_A}+\frac{1}{M_B}}\right), \qquad D_{AB} = \frac{1.857\ x\ 10^{-7}T^{1.5}}{P_t\sigma_{AB}^2\omega_D}\left(\sqrt{\frac{1}{M_A}+\frac{1}{M_B}}\right),$$

$$D_{AB} = \frac{1}{\alpha t_F}\left(\frac{1}{V_1}+\frac{1}{V_2}\right)^{-1} ln\left(\frac{C_{A1,0}-C_{A2,0}}{C_{A1,F}-C_{A0,F}}\right), \qquad D_{AB} = \frac{1.173\,x\,10^{-16}}{\mu_B V_B^{0.6}}(\emptyset m_B)^{0.5}T$$

$$v_{mass,avg} = \sum x_i v_i \qquad v_{mol,avg} = \sum y_i v_i$$

$$\rho g_x - \frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 V_x}{\partial x^2} + \frac{\partial^2 V_x}{\partial y^2} + \frac{\partial^2 V_x}{\partial z^2}\right) = \rho\left(\frac{\partial V_x}{\partial t} + V_x\frac{\partial V_x}{\partial x} + V_y\frac{\partial V_x}{\partial y} + V_z\frac{\partial V_x}{\partial z}\right)$$

$$\rho g_y - \frac{\partial P}{\partial y} + \mu\left(\frac{\partial^2 V_y}{\partial x^2} + \frac{\partial^2 V_y}{\partial y^2} + \frac{\partial^2 V_y}{\partial z^2}\right) = \rho\left(\frac{\partial V_y}{\partial t} + V_x\frac{\partial V_y}{\partial x} + V_y\frac{\partial V_y}{\partial y} + V_z\frac{\partial V_y}{\partial z}\right)$$

$$\rho g_z - \frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 V_z}{\partial x^2} + \frac{\partial^2 V_z}{\partial y^2} + \frac{\partial^2 V_z}{\partial z^2}\right) = \rho\left(\frac{\partial V_z}{\partial t} + V_x\frac{\partial V_z}{\partial x} + V_y\frac{\partial V_z}{\partial y} + V_z\frac{\partial V_z}{\partial z}\right)$$

$$D = D_0 \exp\left(-\frac{Q_d}{kT}\right)$$

Constants

Electron Charge	$q = 1.602 \times 10^{-19}$ C
1 atmosphere pressure	1 atm = 1.013×10^{5} Pa
Gas constant	R =8134 m^3Pa/kmol.K
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ JK^{-1} = 8.62×10^{-5} eVK^{-1}