Assignment MT1-2023-2

Section =1

(Based on lecture notes)

1.1) Derive the equation of continuity in terms of molar flux.

1.2) Considering the steady state diffusion in binary gas mixture derive the equation for the flux for the following cases

- **a.** Diffusion of A through Non diffusing B
- **b.** Equimolar counter diffusion
- **c.** Non-Equimolar counter diffusion
  $C(s) + O_2 = 2CO$

1.3) Considering the steady state diffusion in binary liquid mixture derive the equation for the flux for the following cases

- **a.** Diffusion of A through Non diffusing B
- **b.** Equimolar counter diffusion
- **c.** Non-Equimolar counter diffusion , When, $N_A = N_B/2$

1.4) Show the analogies among Mass, Heat & Momentum transfer.

Section-2

(Based on the work out problems in the text book)

From book: Principle of Mass Transfer by B.K.Dutta

Ex.2.2 Page no.16

EXAMPLE 2.2 (*Diffusion of A through non-diffusing B*) There is a 2 mm thick layer of water on the floor of a room. The water vaporizes and diffuses through a stagnant film of air of estimated thickness of 2.5 mm on the water surface. Under the condition of evaporation, the water temperature is essentially equal to its wet-bulb temperature. If the ambient temperature is 28°C, calculate the time required for the water layer to disappear completely for the following cases: (a) the ambient air has a relative humidity of 60%; and (b) the floor has micropores and water penetrates the floor at a constant rate of 0.1 $kg/m^2 \cdot h$, the ambient air having a humidity as in part (a).

Read the wet-bulb temperature from the humidity chart and calculate the vapour pressure of water using the Antoine equation given below. The diffusivity of water vapour in air is 0.853 ft^2/h at 1 atm and 0°C.

Vapour pressure, p_v (in bar), of water is given by: $\ln p_v = 13.8573 - 5160.2/T$, where T is the temperature in K.

Ex.2.3 page no.18

EXAMPLE 2.3 (*Calculation of flux and velocity*) Ammonia(A) diffuses through a stagnant layer of air(B), 1 cm thick, at 25°C and 1 atm total pressures. The partial pressures of NH_3 on the two sides of the air layer are $p_{A0} = 0.9$ atm and $p_{Al} = 0.1$ atm respectively. Air is non-diffusing. Calculate (a) the molar flux of NH_3, (b) the velocities of the individual components with respect to a stationary observer, (c) the molar and the mass average velocities of the components, and (d) the molar flux of NH_3 with respect to an observer moving with the mass average velocity. Also prepare the plots of partial pressure distributions of ammonia and air along the diffusion path. *Given:* $D_{AB} = 0.214$ cm^2/s.

Ex.2.4 page no .21

EXAMPLE 2.4 (*Flux, velocity and pressure gradient*) A test tube, 1.5 cm in diameter and 12 cm tall, is partly filled with a solution of alkaline pyrogallate. The depth of the empty space above the solution is 5 cm. The temperature is 25°C and the total pressure is 1 atmosphere. Air may be assumed to contain 21% O_2 and 79% N_2. The diffusivity of O_2 in N_2 at the given condition is 0.21 cm^2/s.

(a) Calculate the rate of absorption of oxygen from air in the solution at steady state if air flows gently over the open end of the test tube. Make plots of the distribution of partial pressures of the gases along the diffusion path.
(b) Calculate the partial pressure gradient of oxygen midway in the diffusion path.
(c) Calculate the molar average velocity of the mixture and the 'diffusion velocity' of the two components (O_2 and N_2) at the top end, at the middle and at the liquid surface.
(d) Calculate the flux of the components midway of the diffusion path with respect to an observer moving with twice the molar average velocity at the location in the direction away from the liquid surface.

Ex.2.6 page no.24

EXAMPLE 2.6 (*Equimolar counterdiffusion*) Two large vessels are connected by a tube 5 cm in diameter and 15 cm in length. Vessel 1 contains 80% $N_2(A)$ and 20% $O_2(B)$; vessel 2 contains 20% N_2 and 80% O_2. The temperature is 20°C and the total pressure is 2 atmosphere. Calculate (a) the steady-state flux and the rate of transport of N_2 from vessel 1 to vessel 2, (b) the same quantities for O_2, (c) the partial pressure of N_2 and its gradient in the tube 0.05 m from vessel 1, and (d) the net mass flux with respect to a stationary observer. *Given:* the diffusivity of N_2–O_2 pair is 0.23 cm^2/s at 316 K and 1 atm.

Ex.2.7 Page no .25

EXAMPLE 2.7 (*Non-equimolar counterdiffusion in distillation of a binary mixture*) An aqueous solution of methanol is being separated by distillation in a column. Methanol(A), which is the more volatile component, moves from the liquid phase to the vapour phase while water(B), the less volatile component, gets transported in the opposite direction. At a section of the column,

Ex.2.19 page no 58

EXAMPLE 2.19 Estimate the Knudsen diffusivity of ethylene within a 100 Å pore of a catalyst at 600 K.

Section=3

(Unsolved problems)

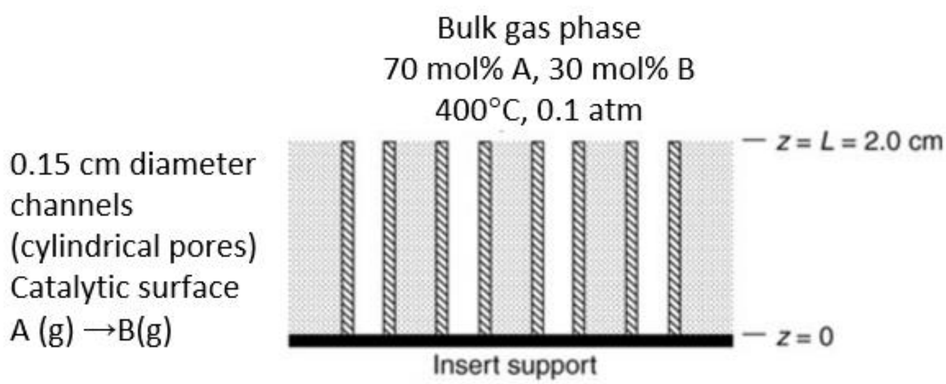
(Assume atmospheric temperature and pressure, and required constants if not mentioned.)

3.1. A cylindrical tank with a diameter of 2 m and total height of 5 m contains liquid methanol (MeOH, molecular weight 32g/mol), which is present at the bottom of a tank at a level of 1 m, open to the atmosphere. The MeOH vapours are quickly dispersed after they leave the tank. The gas space inside is stagnant. At 30°C, liquid MeOH exerts a vapour pressure of 163 mmHg, and at 40°C, that pressure rises to 265 mmHg. The diffusion coefficient of MeOH in air is 1.62×10^{-5} m^2/s at 25°C.

a. What is the rate of MeOH vapour emission from the tank, expressed in kg MeOH/day when the tank is at a temperature of 30°C? State all assumptions and boundary conditions.

b. If the temperature of the tank is raised to 40°C, what is the new methanol emission rate?

3.2. A reactor consists of cylindrical channels which has catalyst coated at its inner walls and a sealed base as shown in the figure. This catalyst promotes isomerization of species A to species B. The gas phase above the channels contains species A at a constant composition of 70% and rest is species B. Gas phase species A diffuses down a straight channel of diameter= 0.15 cm and length= 2 cm. The production rate of B is diffusion limited. The quiescent gas space in the channel consists of only species A and B.



a. State three relevant assumptions for the mass transfer process.

b. Based on your assumptions, simplify the general differential equation for the mass transfer of species A, leaving the equation in terms of the flux N_A.

c. Using equations for the flux of A in your determined equation, express the general differential equation in terms of the concentration c_A.

d. Specify relevant boundary conditions for the gas phase concentration c_A.

3.3. A vapor mixture of A and B is getting distilled when in contact with the liquid solution of A and B. A being more volatile is getting transferred from liquid to vapor phase whereas B is getting transferred in opposite direction. The molecular weight ratio of A/B is around 2.5. The energy required for condensation of B is giving the required energy for vaporization of A. Both are diffusing through a gas film of 0.15 mm thickness. The temperature is 372 K and pressure is 1.013×10^5 Pa. At this condition, the enthalpy of vaporization of A and B are 900 and 2450 kJ/kg, respectively. Develop the flux equation for A vapor. Then develop the flux equation assuming that the components have equimolar heats of vaporization. State the relevant assumptions along with a diagram showing the system.

3.4. Determine the rate of diffusion of butanol at 20 degrees celsius under conditions of unidirectional steady state when the concentrations of butanol on opposite sides of the film are, respectively, 20% and 8% butanol by weight. The thickness of the film in water is 0.5 centimeters. Butanol's diffusivity in aqueous solution is 5.9×10^{-6} centimeters squared per second. At 20 degrees celsius, a solution with 10% butanol has a density of 0.971 g/cc, while a solution with 4% butanol has a density of 0.992 g/cc.

3.5. An absorbent sphere made up of a basic oxide is suspended in a very large volume of a mixture of 70% air and 30% carbon dioxide at a temperature of 40 degrees celsius and a total pressure of 1 atmosphere. The gas is vigorously agitated, and the diffusion of carbon dioxide to the surface of the absorbent takes place through a stationary gas layer that is 3.5 millimeters thick and encircles the sphere. The thickness of the gas is far less than the sphere's radius. Because carbon dioxide is quickly absorbed at the surface of the sphere, the amount of gas that is present there is almost negligible. Determine the rate of carbon dioxide flow as well as the velocity of its diffusion in the middle of the gas layer. The diffusivity of carbon dioxide in air is calculated to be 1.62×10^{-5} m^2/s at 25 degrees Celsius and 1 atmosphere.

3.6. At 25 degrees celsius, oxygen diffuses through a 1 mm-thick layer of stagnant water. On two sides of the film, the concentrations of dissolved oxygen are 0.014 kg/m^3 and 0.008 kg/m^3, respectively. Calculate the oxygen flux while ignoring bulk flow and the concentration profile as a function of the position z within the liquid film.

3.7. A test tube, 5 cm in diameter and 50 cm long, has 5g camphor in it. How long will it take for the camphor to completely sublime into vapor leaving no residue? The pressure is atmospheric and the temperature is 20°C. The sublimation pressure of camphor at this temperature is 97.5 mm Hg, and the diffusivity of camphor is 6.5×10^{-6} m^2/s.