UNIT: V MASS TRANSFER

1. What is mass transfer?

The process of transfer of mass as a result of the species concentration difference in a mixture is known as mass transfer.

2. **Give the examples of mass transfer**.

Some examples of mass transfer.

1. Humidification of air in cooling tower
2. Evaporation of petrol in the carburettor of an IC engine.
3. The transfer of water vapour into dry air.

3. **What are the modes of mass transfer? (Nov/Dec 2010)(Nov/Dec 2104)**

There are basically two modes of mass transfer,

1. Diffusion mass transfer 2. Convective mass transfer

4. **What is molecular diffusion?**

The transport of water on a microscopic level as a result of diffusion from a region of higher concentration to a region of lower concentration in a mixture of liquids or gases is known as molecular diffusion.

5. **What is Eddy diffusion?**

When one of the diffusion fluids is in turbulent motion, eddy diffusion takes place.

6. **What is convective mass transfer? (May/June 2006)**

Convective mass transfer is a process of mass transfer that will occur between surface and a fluid medium when they are at different concentration.

7. **State Fick's law of diffusion**. **(April/May 2012) (NOV-DEC 14)(Nov/Dec 16)**

The diffusion rate is given by the Fick's law, which states that molar flux of an element per unit area is directly proportional to concentration gradient.

$$\frac{ma}{A} = -Dab \frac{dCa}{dx}$$

Where,

$\dfrac{ma}{A}$ – Molar flux, $\dfrac{kg - mole}{s - m^2}$

Dab- Diffusion coefficient of species a and b, m²/s

$\dfrac{dCa}{dx}$ – Concentration gradient, kg/m³

8. What is free convective mass transfer?

If the fluid motion is produced due to change in density resulting from concentration gradients, the mode of mass transfer is said to be free or natural convective mass transfer.

Example: Evaporation of alcohol.

9. Define forced convective mass transfer.

If the fluid motion is artificially created by means of an external force like a blower or fan, that type of mass transfer is known as convective mass transfer.

Example: The evaluation if water from an ocean when air blows over it.

10. Define Schmidt and Lewis number. What is the physical significance of each? (NOV/DEC 13)

The dimensionless Schmidt number is defined as the ratio of momentum diffusivity to mass diffusivity Sc = ν/DAB , and it represents the relative magnitudes of momentum and mass diffusion at molecular level in the velocity and concentration boundary layers, respectively. The Schmidt number diffusivity corresponds to the Prandtl number in heat transfer. A Schmidt number of unity indicates that momentum and mass transfer by diffusion are comparable, and velocity and concentration boundary layers almost coincide with each other.

The dimensionless Lewis number is defined as the ratio of thermal diffusivity to mass diffusivity Le = α / DAB and it represents the relative magnitudes of heat and mass diffusion at molecular level in the thermal and concentration boundary layers, respectively. A Lewis number of unity indicates that heat and mass diffuse at the same rate, and the thermal and concentration boundary layers coincide.

11. Define Sherwood Number. (April/May 2012)

It is defined as the ratio of concentration gradients at the boundary.

$$Sc = \frac{hmX}{D_{ab}}$$

hm- Mass transfer coefficient, m/s

D_{ab}-Diffusion coefficient, m²/s

X- length, m

12. What is mass average velocity?(May/June 2010)

The bulk velocity of mixture , in which different compents mat have different mobilites ,is compared either on mass average . if luid mixture of two components A and B if u_A and u_B are the mean velocties then the average velocity is

u_{mass} = (ρ$_A$ u$_{A+}$ ρ$_B$ u$_B$)/ ρ$_A$ $_+$ ρ$_B$

13. Distinguish between mass concentration and molar concentration (April/May 2017)

Mass Concentration

Mass of a component per unit volume of the mixture. It is expressed in kg/m³

Mass concentration = $\frac{\text{Mass of a component}}{\text{Unit volume of mixture}}$

Molar concentration

Number of molecules of a component per unit volume of the mixture. It is expressed in Kg – mole /m³

Molar concentration= $\frac{\text{Number of moles of component}}{\text{Unit volume of mixture}}$

14. Define schmidt number and state its physical significance.) (Nov/Dec 16)

Schmidt number (Sc) is a dimensionless number defined as the ratio of momentum diffusivity (viscosity) and mass diffusivity, and is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes.

Significance:

Analogous of Prandtl number in Heat Transfer. Used in fluid flows in which there is simultaneous momentum & mass diffusion. It is also ratio of fluid boundary layer to mass transfer boundary layer thickness.

1. **A vessel contains binary mixture of O_2 and N_2 with partial pressure in the ratio 0.21 and 0.79 at 15°C =. The total pressure of the mixture is 1.1 bar. Calculate the following.**

    I. **Molar concentrations**

   II. **Mass densities**

  III. **Mass fractions**

  IV. **Molar fraction of each species.**

[APRIL/MAY 2014; NOV/DEC 2015]

Given:

Partial pressure of O_2 =0.21 x total pressure

    (Po_2)= 0.21 x 1.1

    Po_2= 0.231 x 10^5 N/m^2

So partial pressure of N_2= P_{N2}=86.9 x 10^3 N/m^2

Temperature T = 15° C =288 K

To find

    I. Molar concentrations, Co_2, C_{N2}

   II. Mass densities, ρ_{O2}, ρ_{N2}

  III. Mass fractions, $\dot{m}_{O2}$,$\dot{m}_{N2}$

  IV. Molar fraction of each species.x_{O2}, X_{N2}

Solution:

STEP-1

Molar concentration, $co_2 = \dfrac{po_2}{GT}$

    Universal Gas Constant, G= 8314 J/kg mole K

$$Co_2 = \frac{0.231 \times 10^5}{8314 \times 288}$$

$$Co_2 = 9.64 \times 10^{-3} kg - mole / m^3$$

$$C_{N2} = \frac{p_{N2}}{GT}$$

$$C_{N2} = \frac{86.9 \times 10^3}{8314 \times 288}$$

$$C_{N2} = 0.036 kg - mole/m^3$$

Total concentration,

$$C = C_{O2} + C_{N2} = 0.045 \text{ kg mole}/m^3$$

STEP-2

Molar concentration

$$C = \frac{\rho}{\mu}$$

$$\rho_{O2} = C_{O2} \times \mu_{O2}$$

$$= 9.64 \times 10^{-3} \times 32$$

$$\rho_{O2} = 0.308 kg/m^3$$

$$= 0.0362 \times 28$$

$$\rho_{N2} = 1.013 kg/m^3$$

Overall density, $\qquad \rho = \rho_{O2} \times \rho_{N2}$

$$= 0.308 + 1.10136$$

$$\rho = 1.3216 kg/m^3$$

STEP-3

Mass fractions $\quad \dot{m}_{02} = \dfrac{\rho_{02}}{\rho} = \dfrac{0.308}{1.3216}$

$$\dot{m}_{02} = 0.233$$

$$\dot{m}_{N2} = \frac{\rho_{N2}}{\rho} = \frac{1.0136}{1.3216}$$

$$\dot{m}_{N2} =$$

0.766 **STEP-4**

Mole fractions, $X_{02} = \dfrac{C_{02}}{C} = \dfrac{9.64 \times 10^{-3}}{0.045}$

$$X_{02} = 0.210$$

$$X_{N2} = \frac{C_{N2}}{C} = \frac{0.0362}{0.045}$$

$$X_{02} = 0.804$$

RESULT:

I. Molar concentrations, C_{O_2}, = $9.64 \times 10^{-3} \, kg - mole / m^3$

C_{N_2}, = $C_{N_2} = 0.036 kg - mole / m^3$

II. Mass densities, $\rho_{O_2} = 0.308 kg / m^3$

$\rho_{N_2} = 1.013 kg / m^3$

III. Mass fractions, $\dot{m}_{O_2}$ = 0.233

$\dot{m}_{N_2}$ = 0.766

IV. Molar fraction of each species. X_{O_2} = 0.210

X_{N_2} = 0.804

2. Air at 20°C (ρ = 1.205 kg/m³; υ = 15.06 x 10⁻⁶ m²/s; D = 4.16 x 10⁻⁶ m²/s) flows over a tray (length =32 cm, width = 42 cm) full of water with a velocity of 2.8 m/s. The total pressure of moving air is 1 atm and the partial pressure of water present in the air is 0.00658 bar. If the temperature on the water surface is15°C calculate the evaporation rate of water.

(MAY/JUNE 2012; NOV/DEC 2014; NOV/DEC 2015; APRIL/MAY 2016)

Given:

Fluid temperature, T_∞=20°C

Speed, U = 2.8 m/s

Flow direction is 32 cm side. So, x = 32 cm = 0.32 m

Area, A =32 cm x 42 cm = 0.32x0.42 m²

Partial pressure of water, P_{w_2}=0.0068 bar

P_{w_2}=0.0068 x 10⁵ N/m²

Water surface temperature, Tw = 15°C

To find:

Evaporation rate of water (M_w)

Solution:

Properties of air is given

ρ = 1.205 kg/m³;

υ = 15.06 x 10⁻⁶ m²/s;

Diffusion coefficient D = 4.16×10^{-6} m²/s

STEP-1

$$\text{Re} = \frac{UL}{\nu} = \frac{2.8 \times 0.32}{15.06 \times 10^{-6}}$$

$$= 0.594 \times 10^5 < 5 \times 10^5$$

Since Re < 5×10^5, flow is laminar

Flat plate laminar flow:

Sherwood number (Sh) = $[0.664 \, (\text{Re})^{0.5} \, (\text{Sc})^{0.333}]$.............{1}

[From HMT data book, P.no-175]

STEP-2

Sc → Schmidt number = $\dfrac{\nu}{D_{ab}}$ = $\dfrac{15.06 \times 10^{-6}}{4.16 \times 10^{-5}}$

Sc = 0.3620

Sub Sc, Re in {1}

$$(\text{Sh}) = [0.664 \, (0.594 \times 10^5)^{0.5} \, (0.3620)^{0.333}]$$

Sh= 115.37

STEP-3

Sherwood number Sh = $\dfrac{h_m L}{D_{ab}}$

$$115.37 = \frac{h_m 0.32}{4.16 \times 10^5}$$

h_m= 0.0149 m/s

STEP-4

Mass transfer coefficient based on pressure difference is given

$$h_{mp} = \frac{h_m}{RT_w} = \frac{0.0149}{287 \times 288} \quad \text{[Tw=15°C +273=288 K, So R= 287 J/kg K]}$$

h_{mp}=1.80x10⁻⁷ m/s

Saturation pressure of water at 15°C

P_{w1}=0.017 bar

P_{w1} = 0.017×10^5 N/m²   [From steam table (R.S khurmi) P.no-1]

STEP-5

The evaporation of water

$$M_w = h_{mp} \times A (P_{w_1} - P_{w_2})$$

$$\boxed{M_w = 2.66 \times 10^{-5} \text{ kg/s}}$$

Result:

The evaporation rate of water $M_w = 2.66 \times 10^{-5}$ **kg/s**

3. **Dry air at 27^0c and 1 atm flows over a wet flat plate 50 cm long at a velocity of 50 m/s. Calculate the mass transfer coefficient of water vapour in air at the end of the plate.**

(NOV/DEC 2014; APRIL/MAY 2015) (NOV/DEC

Given:

Fluid temperature $T_\infty = 27^0c$

Velocity $u = 50$ m/s

Length $x = 35$mm $= 0.035$ m

To find:

Mass transfer co-efficient,(h_m)

Solution:

STEP-1

Properties of at 27^0C:

$V = 16 \times 10^{-6}$ m^2/s

$\text{Re} = \dfrac{UL}{v} = \dfrac{50 \times 0.035}{16 \times 10^{-6}}$

$= 1.09375 \times 10^5 < 5 \times 10^5$

Since Re $< 5 \times 10^5$, flow is laminar

Flat plate laminar flow:

Sherwood number (Sh) = $[0.664 \, (\text{Re})^{0.5} \, (\text{Sc})^{0.333}]$.............**{1}**

[From HMT data book, P.no-175]

STEP-2

[D_{ab}-Diffusion coefficient (water+ air) @ $27^0c = 25.38 \times 10^{-6}$ m^2/

binils - Anna University App on Play Store

$$Sc \rightarrow \text{Schmidt number} = \frac{v}{D_{ab}} = \frac{16 \times 10^{-6}}{25.38 \times 10^{-6}}$$

Sc = 0.6304

STEP-3

Sub Sc, Re in {1}

(Sh) = [0.664 (1.09375 x 10^5)$^{0.5}$ (0.6304)$^{0.333}$]

Sh= 188.32

STEP-4

Sherwood number Sh = $\dfrac{h_m L}{D_{ab}}$

$$188.32 = \frac{h_m 0.35}{25.38 \times 10^{-6}}$$

h$_m$= 0.1365 m/s

Result:

Mass transfer coefficient of water vapour **h$_m$= 0.1365 m/s.**

4. **CO_2 and air experience equimolar counter diffusion in a circular tube whose length and diameter are 1 m and 50 mm respectively. The system of total pressure of 1 atm and a temperature of 25^{0}C. The ends of the tube are connected to large chambers in which the species concentrations are maintained at fixed values.the partial pressure of CO_2 at one end is 190 mm of Hg while at the other end is 95 mm Hg . Estimate the mass transfer rate of CO_2 and air through the tube.**

[MAY/JUNE 2012; APRIL/MAY 2016]

Given:

Diameter,d=50mm=0.05m

Length=1m [x_2-x_1]

Total pressure ,p=1 atm =1bar

Temperature,T=25^{0}C= 298 K

Parital pressure of CO_2 at one end

$$P_{a1}=190\text{mm of Hg}= \frac{190}{760} \text{ bar}$$

$$P_{a1}= 0.25 \text{bar} \quad [1\text{bar}= 760 \text{ mm of Hg}]$$

$$P_{a1}= 0.25 \times 10^5 \text{N/m}^2 \quad [1 \text{ bar} = 10^5 \text{ N/mm}^2]$$

Parital pressure of CO_2 at other end

$$P_{a2}=95\text{mm of Hg}= \frac{95}{760} \text{ bar}$$

$$P_{a2}= 0.0312 \text{ bar} \quad [1\text{bar}= 760 \text{ mm of Hg}]$$

$$P_{a2}= 0.0312 \times 10^5 \text{N/m}^2 \quad\quad [1 \text{ bar} = 10^5 \text{ N/mm}^2]$$

To find:

1. Mass transfer rate of Co_2

2. Mass transfer rate of air

Solution:

STEP-1

$$\frac{m_a}{A} = \frac{D_{ab}}{GT} \frac{[C_{a1} - C_{a2}]}{[X_2 - X_1]}$$

Diffusion coefficient (D_{ab}) for CO_2-Air combination is 11.89×10^{-6} m²/s

[HMT data book page no.180]

G-Universal gas constant -8314 $\dfrac{J}{kg - mole - K}$ (J/kg-mole-K)

A-Area $= \dfrac{\pi}{4}$ (d)²

A=1.9634x10⁻³ m²

$$\frac{m_a}{A} = \frac{D_{ab}}{GT} \frac{[C_{a1} - C_{a2}]}{[X_2 - X_1]}$$

$$\frac{m_a}{A} = \frac{11.89 \times 10^{-6}}{8314 \times 298} \frac{[0.25 \times 10^5 - 0.031 \times 10^5]}{[1]}$$

Molar transfer rate of Co_2, m_a = 1.050 x 10⁻⁷ $\dfrac{kg - mole}{s}$

STEP-2

We know,

Mass Transfer Rate Co_2 = Molar Transfer x Molecular Weight

$$= 1.050 \times 10^{-7} \times 44.01$$

[Molecular weight of Co_2 Refer HMT D.B Page 182]

Mass Transfer Rate Co_2 = 4.625 x 10⁻⁶ kg/s

Mass Transfer Rate of Air **= m$_b$= -**1.050 x 10^{-7} $\dfrac{kg - mole}{s}$

STEP-3

[m$_a$= -m$_b$]

Mass Transfer Rate Air = Molar Transfer x Molecular Weight of air

$$= 1.050 \times 10^{-7} \times 29$$

Mass Transfer Rate Air = -3.045 x 10^{-6} kg/s

Result:

1. Mass transfer rate of Co2 = **4.625 x 10^{-6} kg/s**

2. Mass transfer rate of air = **-3.045 x 10^{-6} kg/s**

5. **Discuss briefly the Analogy between heat and mass transfer.**

[MAY/JUNE 2013; NOV/DEC 2015; APRIL/MAY 2016]

There is similarity among heat and mass transfer. The three basic equations dealing with these are

    I.   Newtonian equation of momentum

    II.   Fourier law of heat transfer

    III.   Fick law of mass transfer

The momentum, heat and mass transfer equation can be written as

Continuity equation, $\dfrac{\partial u}{dx} + \dfrac{\partial v}{dy} = 0$

Momentum transfer, $u\dfrac{\partial u}{dx} + v\dfrac{\partial v}{dy} = v\dfrac{\partial^2 u}{dy^2}$

Heat transfer, $u\dfrac{\partial T}{\partial x} + v\dfrac{\partial T}{\partial y} = \alpha\dfrac{\partial^2 u}{\partial y^2}$

Mass transfer, $u\dfrac{\partial Ca}{\partial x} + v\dfrac{\partial Cn}{\partial y} = D\dfrac{\partial^2 Ca}{\partial y^2}$

Heat and mass transfer takes place due to temperature difference. As per Fourier's law of conduction

$$Q = -kA\dfrac{dt}{dx}$$

Where   Q= rate of heat transfer

                K= thermal conductivity of material

A= Heat transfer area

$\dfrac{dt}{dx}$ = Temperature gradient

As per Newton's law of cooling

$$Q = hA\Delta T$$

Where h= heat transfer coefficient

Mass transfer takes place due to concentration difference.
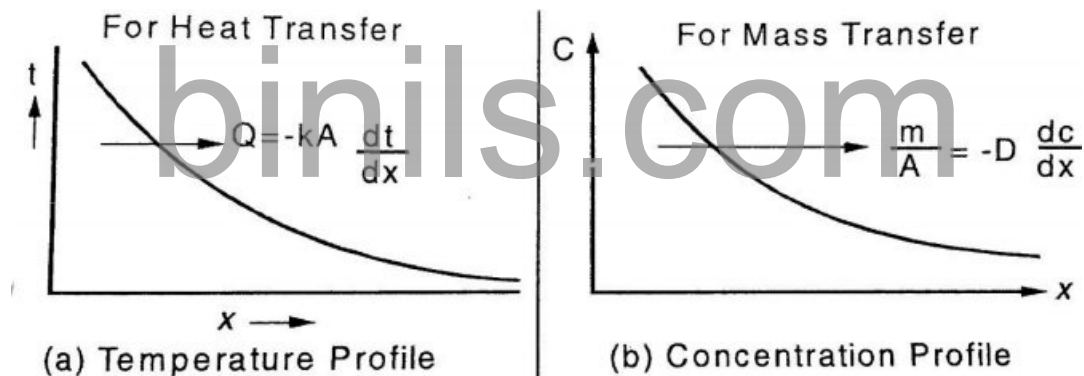
As per Fick's law of diffusion

$$Na = \dfrac{m_A}{A} = -D_{AB}\ \dfrac{dC_A}{dx}$$

m_A = Mass flow rate of species A by diffusion.

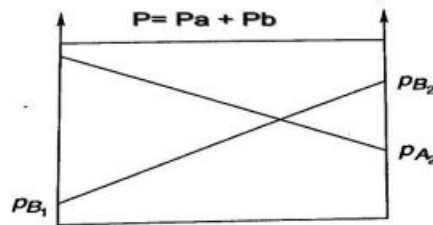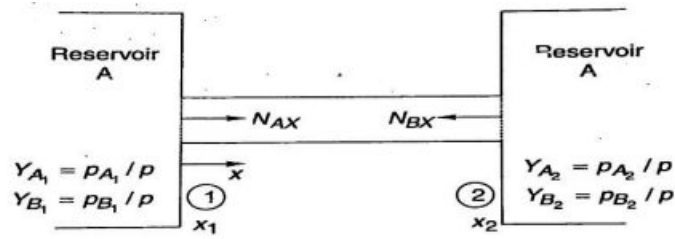A = Area through which mass is flowing

D_{AB} = Diffusion coefficient.

$\dfrac{dC_A}{dx}$ = concentration gradient.

(a) Temperature Profile   (b) Concentration Profile

6. Explain Equimolar Counter diffusion in gases.

[APRIL/MAY 2013; NOV/DEC 2014]

Two large chambers 'a' and 'b' connected by a passage as shown below.

Equimolar Counter Diffusion in a Binary Mixture

Na and Nb are the steady state molar diffusion rates of component a and b respectively.

Equimolar diffusion is defined as each molecule of 'a' is replaced by each molecule of 'b' and vice versa. The total pressure $p = pa + pb$ is uniform throughout the system.

$$P = Pa + Pb$$

Differentiating with respect to x

$$\frac{dP}{dx} = \frac{dPa}{dx} + \frac{dPb}{dx}$$

Since the total pressure of the system remains constant under steady state conditions

$$\frac{dP}{dx} = \frac{dPa}{dx} + \frac{dPb}{dx} = 0$$

$$\frac{dPa}{dx} = -\frac{dPa}{dx}$$

Let the total molar flux is zero, Na + Nb = 0

→ Na = -Nb

From flick's law,
$$-D_{BA} \frac{A}{GT} \frac{dPa}{dx} = D_{BA} \frac{A}{GT} \frac{dPb}{dx}$$

$$D_{AB} = D_{BA} = D$$

$$Na = \frac{ma}{A} = -D \frac{A}{GT} \int_1^2 \frac{dPA}{dx}$$

Molar flux,

$$Na = \frac{ma}{A} = -D \frac{A}{GT} \left[\frac{Pa1 - Pa2}{x2 - x1} \right]$$

Similarly,

$$Nb = \frac{mb}{A} = -D \frac{A}{GT} \left[\frac{Pb1 - Pb2}{x2 - x1} \right]$$

Where,

$\dfrac{ma}{A}$ – Molar flux $\dfrac{kg - mole}{s - m^2}$

D- Diffusion coefficient

G- Universal constant- 8314 $\dfrac{J}{kg - mole - K}$

A- Area – m²

Pa1- Partial pressure of constituent at 1 in N/m²

Pa2- Partial pressure of constituent at 2 in N/m²

T – Temperature – K

7. **An open pan of 150 mm diameter and 75 mm deep contains water at 25ᵒC and is exposed to atmosphere air at 25ᵒC and 50ᵒC R.H. calculate the evaporation rate of water in grams per hour.**

[APRIL/MAY 2002]

Given:

Diameter, d = 150 mm = 0.150 m

Deep, (x_2-x_1) = 75 mm = 0.075 m

Temperature, T = 25ᵒC+273 = 298 K

Relative Humidity = 50%

To Find:

Evaporation rate of water in grams per hour.

Solution:

Diffusion co-efficient (D_{ab}) [water + air] at 25ᵒC

[From HMT data book, page no, 180]

D_{ab} = 25.83 x 10^{-6} m^2/s

STEP-1

We know that, for isothermal evaporation,

Molar flux, $\dfrac{ma}{A} = \dfrac{D_{ab}}{GT} \dfrac{p}{(x_2 - x_1)} \ln\left[\dfrac{P - Pw2}{P - Pw1}\right]$

Atmospheric air 50% RH

Area, A = 0.0176 m^2

P = Total pressure = 1 atm = 1.013 x 10^5 N/mm^2

Pw1 = Partial pressure at the bottom of the test tube corresponding to saturation temperature 25°C.

At 25°C

➔ Pw1 = 0.03166 x 10^5 N/mm^2 [From steam table p.no 2]

Pw2 = Partial pressure at the top of the pan corresponding to 25°C and 50°C relative humidity.

At 25°C

➔ Pw2 = 0.03166 x 10^5

R.H = 50% = 0.50

Pw2 = 0.03166 x 10^5 x 0.50

➔ Pw2 = 1583 N/m^2

STEP-2

$\dfrac{ma}{0.076} = \dfrac{25.83 \times 10^{-6}}{8314 \times 298} \times \dfrac{1.013 \times 10^5}{0.075} \ln\left[\dfrac{1.013 \times 10^5 - 1583}{1.013 \times 10^5 - 0.03166 \times 10^5}\right]$
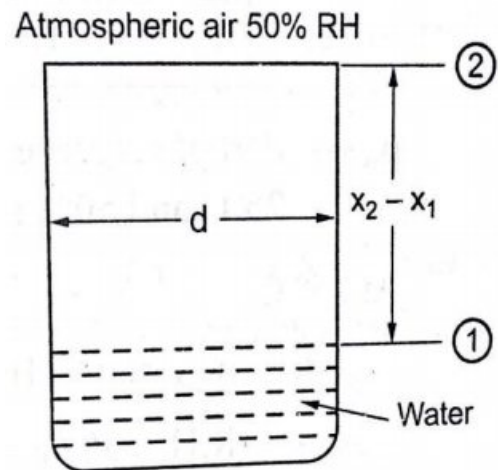
Molar rate of water vapour, ma = 3.96 x10^{-9} $\dfrac{kg - mole}{s}$

STEP-3

Mass rate of water vapour = molar rate of water vapour X molecular weight of steam

= 3.96 x 10^{-9} x 18.016 kg/s

Mass rate of water vapour = 0.256 g/h

Result:

Evaporation rate of water = 0.256 g/h.

> **Evaporation rate of water = 0.256 g/h.**

1. **Two large tanks ,maintained at the same temperature and pressure are connected by a circular 0.15m diameter direct, which is 3 m length .One tank contains a uniform mixture 0f 60 mole % ammonia and 40 mole % air and other tank contains a uniform mixture of 20 mole % ammonia and 80 mole % air. The system is at 273 K and 1.013 x 10 ^{5} pa . Determine the rate of ammonia transfer between the two tanks.Assuming a steady state mass transfer.**

Given:

Diameter d= 0.15 m

Length (x_2-x_1)=3 m

$Pa1= \dfrac{60}{40}$ =0.6 bar = 0.6 x 10^5 N/m^2

$Pb1= \dfrac{40}{40}$ =0.4 bar = 0.4 x 10^5 N/m^2

$Pa2= \dfrac{20}{40}$ =0.2 bar = 0.2 x 10^5 N/m^2

$Pb2= \dfrac{80}{40}$ =0.8 bar = 0.8 x 10^5 N/m^2

T= 273 K

P=1.013 x 10^5 N/m^2
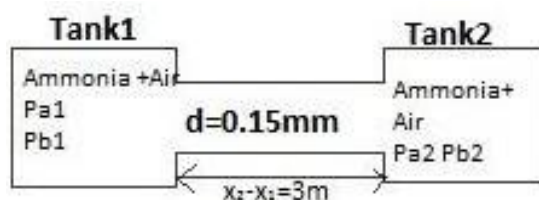
a-Ammonia

b-Air

To find

Rate of ammonia transfer

Solution:

Equimolar counter diffusion

Molar flux,

$$\frac{ma}{A} = \frac{Dab}{GT}[\frac{Pa1 - Pa2}{X2 - X1}\}$$

Where G –universal constant =8314 J/Kg-mole-K

A= area= $\frac{\pi}{4}d^2$

A= $\frac{\pi}{4}(0.15)^2$

A=0.017 m^2

Dab-Diffusion co efficient of ammonia with air = 21.6 x 10^{-6} m^2/s
(From HMT data book P.No 180 (sixth edition)

Dab = 21.6 x 10^{-6} m^2/s

$$(1) = \frac{ma}{0.017} = \frac{21.6\ X\ 10^{-6}}{8314\ X\ 273}X\frac{0.6\ X\ 10^5 - 0.2\ X\ 10^5}{3}$$

Molar transfer rate of ammonia ,m$_a$ = 2.15 X 10^{-9} Kg-mole/s

Mass transfer rate of ammonia = Molar transfer rate of ammonia x Molecular weight of ammonia

= 2.15 X 10^{-9} x17.03 (Refer HMT data book P.No 182)

Mass transfer rate of ammonia = 3.66 x 10^{-8} Kg/s

Result

Mass transfer rate of ammonia = 3.66 x 10^{-8} Kg/s

2. An open pan 20cm in diameter and 8 cm deep contains water at 25°C and is exposed to dry atmospheric air.If the rate of diffusion of water vapour is 8.5 x 10^{-4} kg/h, estimate the diffusion co efficient of water in air.

Given :

Diameter d= 20 cm = 0.20 m

Length (x$_2$-x$_1$) = 8 cm = 0.08 m

Temperature T = 25°C + 273 = 298 K

Diffusion rate (or)

Mass rate of water vapour = 8.54 x 10^{-4} kg/h

$$= \frac{8.54 \times 10^{-4} \, kg}{3600 \, s}$$

$$= 2.37 \times 10^{-7} \text{ kg/s}$$

To find

Diffusion co efficient Dab
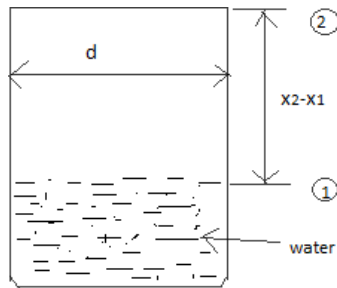
Solution

Molar rate of water vapour

$$\frac{ma}{A} = \frac{Dab}{GT} \frac{p}{x_2 - x_1} X \ln\left[\frac{p - p_{w2}}{p - p_{w1}}\right]$$

$$m_a = \frac{Dab \, X \, A}{GT} \frac{p}{x_2 - x_1} X \ln\left[\frac{p - p_{w2}}{p - p_{w1}}\right]$$

We know that

Mass transfer rate of steam = Molar transfer rate of steam x Molecular weight of steam

$$2.37 \, X10^{-7} = \frac{Dab \, X \, A}{GT} \frac{p}{x_2 - x_1} X \ln\left[\frac{p - p_{w2}}{p - p_{w1}}\right] X \, 18.016$$

Where

Area A= $\frac{\pi}{4}d^2$

$= \frac{\pi}{4}(0.20)^2$

A= 0.0314 m²

G –universal constant =8314 J/Kg-mole-K

P- Total Pressure = 1 atm = 1.013 bar = 1.013 x 10⁵ N/m²

Pw₁- Partial pressure at the bottom of the test tube corresponding to saturation temperature $25°C$

At $25°C$ (From Rs Khurmi Steam table P.No 2)

$$Pw_1 = 0.03166 \times 10^5 \text{ N/m}^2$$

Pw₂- Partial pressure at the top of the pan Hence air is dry and there is no water vapour So, $Pw_2 = 0$

$$\boxed{Pw_2 = 0}$$

(1) =

$$2.37 \times 10^{-7}$$
$$= \frac{Dab \times 0.0314}{8314 \times 298} \times \frac{1.013 \times 10^5}{0.08} \times \ln\left[\frac{1.013 \times 10^5 - 0}{1.013 \times 10^5 - 0.03166 \times 10^5}\right] \times 18.016$$

$$\boxed{Dab = 2.58 \times 10^5 \text{ m}^2/\text{s}}$$

Result

Diffusion coefficient , Dab = 2.58 x 10⁵ m²/s

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