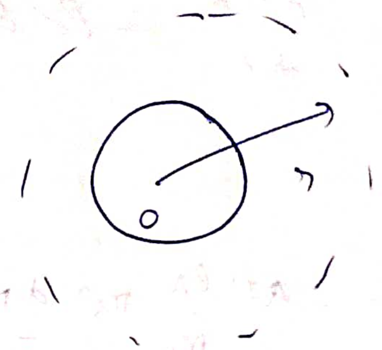
Assignment - 3

Section 1

1.1. (a)



By continuity in steady state,

$$N_A \times A = \text{const.} = W \text{ (say)}$$

↳ area

$$\therefore N_A = \frac{W}{4\pi r^2}$$

Now,

$$N_A = -\frac{D_{AB}}{RT}\frac{dP_A}{dr} + N_A\frac{P_A}{P}$$

$$\therefore N_A = -\frac{D_{AB} P \, dP_A}{RT(P-P_A)\, dr}$$

$$\therefore -\frac{dP_A}{dr}\frac{D_{AB} P}{RT(P-P_A)} = \frac{W}{4\pi r^2}$$

$$\therefore -\int_{P_{A\infty}}^{P_{As}} \frac{dP_A \, D_{AB} P}{RT(P-P_A)} = \int_{\infty}^{R} \frac{W}{4\pi r^2}\, dr$$

$$\therefore \ln\left(\frac{P-P_{A\infty}}{P-P_{As}}\right) = \frac{RTW}{4\pi D_{AB} P R} \quad -(1)$$

↳ surface

↳ $\lim_{r\to\infty} \frac{1}{r} = 0$

$$\therefore \boxed{W = \frac{4\pi D_{AB}}{RT} P r_s \ln\left(\frac{P - P_{A\infty}}{P - P_{As}}\right)}$$

Now,

$$W = \frac{dn_A}{dt} = \frac{d}{dt}\left(\frac{\frac{4}{3}\pi r_s^3 \rho_A}{M_A}\right)$$

mass

molecular mass

$$= -\frac{4\pi \rho_A}{M_A} r_s^2 \frac{dr_s}{dt}$$

$$\therefore \frac{4\pi \rho_A}{M_A} r_s^2 \frac{dr_s}{dt} = \frac{4\pi D_{AB}}{RT} P r_s \ln\left(\frac{P - P_{A\infty}}{P - P_{As}}\right)$$

$$\therefore -\int_{r_{s0}}^{r_s'} r_s \, dr_s = \frac{D_{AB} P M_A}{RT \rho_A} \ln \frac{P - P_{A\infty}}{P - P_{As}} \int_0^{t'} dt$$

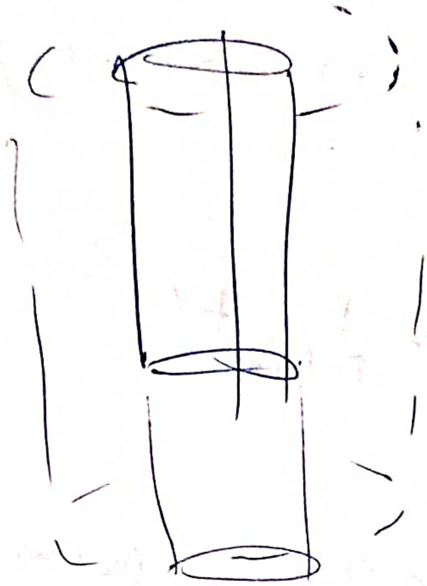
$$\therefore r_{s0}^2 - r_s'^2 = \frac{2 D_{AB} P M_A t'}{RT \rho_A} \ln\left(\frac{P - P_{A\infty}}{P - P_{As}}\right)$$

$r_s = 0$ at the end

$$\therefore \boxed{t' = \frac{r_{s0}^2 RT \rho_A}{2 D_{AB} P M_A \ln\left(\frac{P - P_{A\infty}}{P - P_{As}}\right)}}$$

spherical geometry

Q2 (b)



$$(2\pi r L)\, N_A = w \Rightarrow N_A = \frac{w}{2\pi r L}$$

(const)

$$\therefore \frac{D_{AB} P}{RT(P - P_A)} \frac{dP_A}{dr} = \frac{w}{2\pi r L}$$

$$\therefore \frac{dP_A}{P - P_A} = \frac{w RT}{2\pi L D_{AB} P} \frac{dr}{r}$$

$$\therefore \ln\left(\frac{P - P_{A\delta}}{P - P_{A_0}}\right) = \frac{w RT}{2\pi L D_{AB} P} \ln\left(\frac{r_c + \delta}{r_c}\right)$$

$$\therefore \ln \frac{P}{P - P_{A0}} = \frac{w RT}{2\pi L D_{AB} P} \ln\left(1 + \frac{\delta}{r_c}\right)$$

$$\therefore w = \frac{2\pi L}{D_{AB} P} \frac{\ln \frac{P}{P - P_{A0}}}{\ln\left(1 + \frac{\delta}{r_c}\right)}$$

$$= \cancel{2\pi} - \frac{d\, \pi r^2 L \frac{\rho}{M_A}}{dt}$$

$$= -2\pi L \frac{\rho}{M_A} r_c \frac{dr_c}{dt}$$

$$\therefore \int_{r_c}^{r_{c2}} \ln\left(1 + \frac{\delta}{r_c}\right) dr_c = \frac{D_{AB} P}{RT} \frac{M_A}{\rho_A} \ln\left(\frac{P}{P - P_{A0}}\right) \int_0^t dt$$

$$\Rightarrow \int_{r_{c1}}^{r_{c2}} \left(r_c \ln(r_c + \delta) - r_c \ln r_c \right) dr$$

$$= \frac{D_{AB} P}{RT} \frac{M_A}{\rho_A} \ln \frac{P}{P - P_{A0}} t'$$

$$\therefore \Bigg[\frac{(r_c+\delta)^2}{2} \ln (r_c+\delta) - \frac{(r_c+\delta)^2}{4}$$

$$- \delta \left((r_c+\delta) \ln (r_c+\delta) - (r_c+\delta) \right)$$

$$- \frac{r_c^2}{2} \ln r_c + \frac{r_c^2}{4} \Bigg]_{r_{c1}}^{r_{c2}}$$

$$= \frac{D_{AB} P}{RT} \frac{M_A}{\rho_A} \ln \frac{P}{P - P_{A0}} t'$$

$$\frac{1}{2} r_{c1}^2 \ln\left(1 + \frac{\delta}{r_{c1}}\right)$$

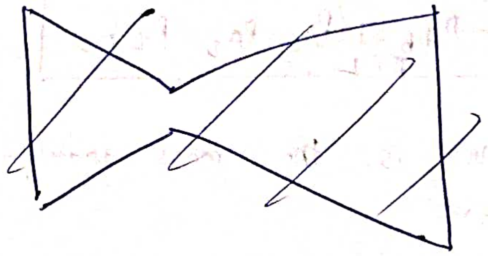
$$- \frac{1}{2} r_{c2}^2 \ln\left(1 + \frac{\delta}{r_{c2}}\right)$$

$$+ \frac{\delta}{2} \left[(r_{c1} - r_{c2}) - \delta \ln \left(\frac{r_{c1}+\delta}{r_{c2}+\delta} \right) \right]$$

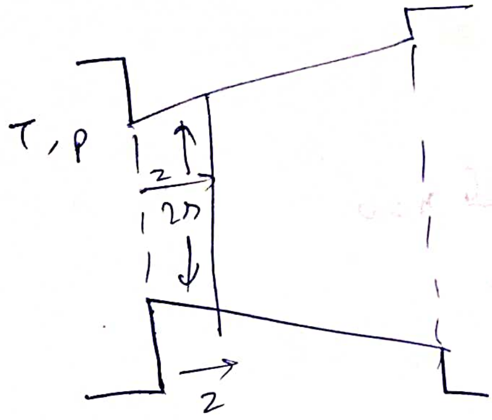
$$= \frac{D_{AB} P M_A}{RT \rho_A} \ln \left(\frac{P}{P - P_{A0}} \right) t'$$

$$\boxed{\therefore t' = \frac{1}{2} \frac{RT\rho_A}{D_{AB} P M_A} \left(r_{c1}^2 \ln\left(1+\frac{\delta}{r_{c1}}\right) - r_{c2}^2 \ln\left(1+\frac{\delta}{r_{c2}}\right) + \delta \left[(r_{c1} - r_{c2}) - \delta \ln \left(\frac{r_{c1}+\delta}{r_{c2}+\delta} \right) \right] \right)}$$

~~(C)~~



(C)



Equimolar counterdiffusion

$N_A \pi r^2 = const = W_2$ (say)

$\rightarrow N_A = -N_B \Rightarrow N_A + N_B = 0$

$N_A = -\frac{D_{AB}}{RT}\frac{dP_A}{dz} + \frac{0}{P} P_A$

$\therefore N_A \pi r^2 = -\frac{D_{AB}\pi}{RT} r^2 \frac{dP_A}{dz} = \cancel{const} \; W_2$

$\frac{dz}{dr} = \frac{L}{R_2 - R_1}$

$\therefore dz = \frac{L\,dr}{R_2 - R_1}$

$\therefore r^2 \frac{dP_A}{L\,dr}(R_2 - R_1) \; W_1 = const$

$= \frac{\cancel{r^2}R}{L} - \frac{dP_A}{d\left(\frac{1}{r}\right)} \frac{(R_2 - R_1)}{L}$

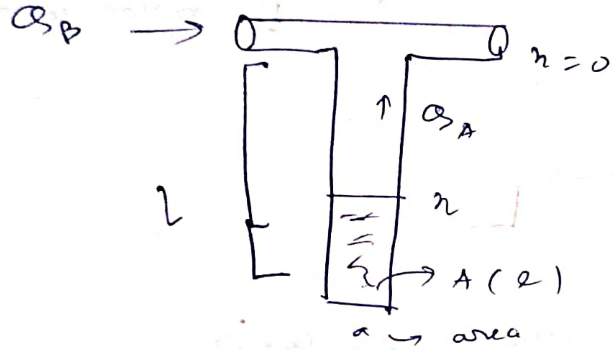
$= -\frac{\delta P_A}{\delta \frac{1}{r}\Big|_{R_2, R_1}} \frac{(R_2 - R_1)}{L}\Big|_{R_2, R_1} = -\frac{P_{A_2} - P_{A_1}}{R_2^{-1} - R_1^{-1}} \frac{(R_2 - R_1)}{}$

$= \frac{(P_{A_2} - P_{A_1}) R_1 R_2}{L}$

$$\therefore \boxed{W_A = -\frac{D_{AB}\,\pi\,(P_{A_2} - P_{A_1})R_1 R_2}{RTL}}$$

↳ This is the mass transfer rate.

1.2. ~~...~~ Stefan tube



~~In~~ In Stefan tube apparatus, we take a volatile liquid phase whose D_{AB} is to measured, (although high volatility is not a must). Let that liquid be A. ~~...~~ It diffuses upwards ~~to~~ in the the tube, ~~...~~ and a high flow rate of another component B sweeps away the incoming A vapour.

Thus,

$$Q_B >> Q_A$$

Since ~~E, T~~ T, P is const.

$$D_{AB} = f(P, T) \text{ is const.}$$

A diffusing, B non diffusing assumed

We measure the D_{AB} from the depletion rate of level ~~L~~ x of the liquid.

In steady state,

$$N_A = \frac{D_{AB}\, c\, (C_{A1} - C_{A2})}{x\, C_{B,lm}}$$

$$= \frac{D_{AB}\, c}{x} \ln \frac{C_A - c}{C_{A2} - c}$$

$$= \frac{d}{dt}\left(a(L - x)\, C_{A(l)}\right)$$

$$= -\frac{d}{dt}\, a(L-x)\, \frac{\rho_A}{M_A}$$

$$= \frac{\rho_A\, a}{M_A} \frac{dx}{dt}$$

$$\therefore \frac{dx}{dt} = \frac{D_{AB}}{x} \frac{M_A}{\rho_A} \frac{c}{a} \ln\left(\frac{C_A - c}{C_{A2} - c}\right)$$

$C_A \to 0$ (as swept away)

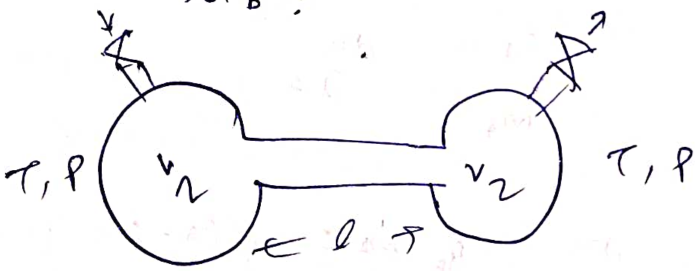
C_{A2} is const. (known)

$$\therefore \frac{L^2}{2} = \frac{D_{AB}\, M_A}{\rho_A} \frac{c}{a} \ln\left(\frac{C_A - c}{C_{A2} - c}\right) t$$

↳ time of sublimation

$$\therefore \boxed{D_{AB} = \frac{\rho_A L^2{}_0\, t}{2 M_A c} \ln\left(\frac{c}{c - C_{A2}}\right)}$$

1.3. Twin bulb:



In this setup, two bulbs of unequal volumes are maintained at const. T, P. ~~We~~

~~The One~~ can Both contain unequal concentrations A, B which ~~can be~~ can be measured.

Here too, we exploit the ~~concept of~~ time taken to diffuse and change in concentration to infer the D_{AB}.

Equimolar Counter diffusion takes place,

so $N_A = -N_B$

$\therefore$ In steady state,

$$N_A = -N_B = \frac{D_{AB}}{l} \,\cancel{a}\, \frac{(C_{A1} - C_{A2})}{\cancel{C_{Atm}}} \rightarrow \text{const. geometry}$$

Now,

$$N_A a = -\frac{d}{dt}(V_1 C_{A1}) = \frac{d}{dt}(V_2 C_{A2})$$

$$\therefore N_A a \left(\frac{1}{V_1} + \frac{1}{V_2}\right) = \frac{d}{dt}(-C_{A1}) + \frac{d}{dt}(C_{A2})$$

$$= -\frac{d}{dt}(C_{A1} - C_{A2})$$

$$\therefore \frac{D_{AB}}{l}(C_{A1} - C_{A2})\, a \left(\frac{1}{V_1} + \frac{1}{V_2}\right) = -\frac{d}{dt}(C_{A1} - C_{A2})$$

$$\therefore \frac{D_{AB}}{l} a \left(\frac{1}{V_1} + \frac{1}{V_2}\right) \int_0^t dt = -\int_0^t \frac{d(C_{A1} - C_{A2})}{(C_{A1} - C_{A2})\, dt}$$

$$\therefore \boxed{D_{AB} = \frac{-\left[\ln(C_{A1} - C_{A2})\right]_{t=0}^{t=t}\, l}{t\, a \left(\frac{1}{V_1} + \frac{1}{V_2}\right)}}$$

when t can be chosen as per convenience.

2.4. Ways to obtain Mass Transfer Coefficient :

(i) Analytical → (a) Film theory

(b) Penetration theory

(c) Surface renewal theory

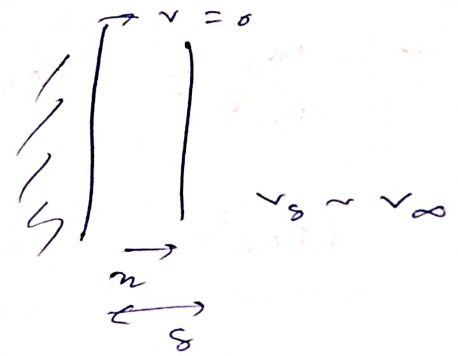
(d) Boundary layer theory

(ii) Experimental correlations → (a) Based on actual experimental data

(b) Based on analogy

1.5. (d) <u>Boundary Layer Theory</u>:

In this theory, we assume the formation of a velocity boundary layer : a layer whose terminal velocity is ~ free stream velocity



By ~~For~~ We assume that boundary layer is Laminar.

Thus, by definition of Sherwood Number (local),

$$Sh_x = \frac{k_{L,x}\, x}{D_{AB}} = 0.332 \underbrace{(Re_x)^{\frac{1}{2}}}_{\text{Reynold's no.}} \underbrace{(Sc)^{\frac{1}{3}}}_{\text{Schmidt No.}}$$

(by heat transfer analogy)

$$\therefore Sh_{av} = \frac{k_{L,av}\, L}{D_{AB}} = 0.332 \frac{\int_0^L Re_x\, dx}{\int_0^L x} (Sc)^{\frac{1}{3}}$$

$$= 0.664\, Re_L^{\frac{1}{2}} Sc^{\frac{1}{3}}$$

$$\therefore \boxed{k_L(av) = \frac{D_{AB} \times 0.664}{L} Re_L^{\frac{1}{2}} Sc^{\frac{1}{3}}}$$

~~This is the MTC~~.

~~Now,~~ $Sc = \frac{\nu}{\rho D}$

$\therefore \quad k_L \propto D_{AB} \times Sc^{\frac{1}{3}}$

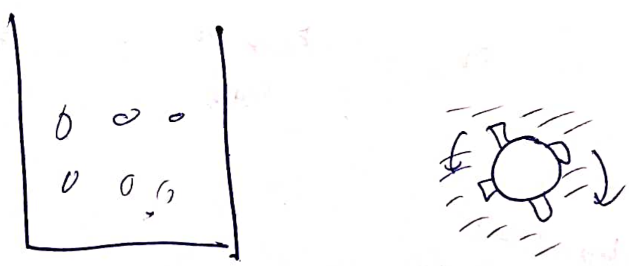
Now, $Sc \propto = \frac{\nu}{\rho D_{AB}} \propto \frac{1}{D_{AB}}$

$\therefore \quad k_L \propto \frac{D_{AB}}{D_{AB}^{\frac{2}{3}}} = D_{AB}^{\frac{2}{3}}$

$\therefore \quad \boxed{k_L = k\, D_{AB}^{\frac{2}{3}} \quad ; k = 0.664\, Re^{\frac{1}{2}} \left(\frac{\nu}{\rho}\right)^{\frac{1}{3}}}$

The fluid flow carries away any incipent mass transfer thereby maintaining a steady rate.

b) Penetration Theory :



~~Assumptions : (i) Unsteady mass transfer~~

Assume a spherical ~~droplet~~ bubble. The mass transfer occurs on the surface, by liquid element sliding from the top, and leaving at the bottom after time t_c.

Assumptions:

(a) Unsteady state Mass transfer

(b) Equilibrium at interface

(c) Each liquid element has same t_c.

Thus, $t_c = \frac{d_b}{v_b}$ → diameter of ~~the~~ bubble

v_b → speed

We use the ~~2nd~~ generalised 2nd Law:

$$D_{AB} \frac{\partial^2 C_A}{\partial z^2} = \frac{\partial C_A}{\partial t} \quad \text{(other terms are 0)}$$

The solution of this diff. eqn. is
are

$$\frac{C_A - C_{Ab}}{C_{Ai} - C_{Ab}} = 1 - \operatorname{erf} \eta \rightarrow \operatorname{erf} \eta$$

$$= \frac{2}{\sqrt{\pi}} \int_0^{\eta} e^{-t^2} dt$$

$$\therefore N_A(t) = D_{AB} \frac{\partial C_A}{\partial z} \quad \text{(by Fick's Law)}$$

$$= \sqrt{\frac{D_{AB}}{\pi t}} (C_{Ai} - C_{Ab})$$

$$\therefore N_{A\,av} = \frac{\int N_A(t)\, dt}{\int dt} = 2\sqrt{\frac{D_{AB}}{\pi t_c}} (C_{Ai} - C_{Ab})$$

$$\therefore N_{A\,av} \propto \frac{2\sqrt{D_{AB}}(C_{Ai} - C_{Ab})}{\sqrt{t_c}}$$

$$= k\,(C_{Ai} - C_{Ab})$$

$$\therefore \boxed{k_{L\,av} \propto \frac{2\sqrt{D_A}}{\sqrt{t_c}} = 2\sqrt{\frac{D_{AB}}{\pi t_c}}}$$

t_c is a model parameter.

(c) Surface renewal theory

Here, we improve upon the Penetration theory:
there is a distribution of t_c.

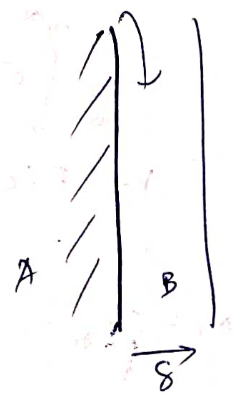
The end result for is found to be

$$\boxed{k_L = \sqrt{D_{AB}\, s}}$$

$\therefore$ $k_L \propto \sqrt{D_{AB}}$

where s is rate of surface renewal

(a) Film Theory:



Here, we assume

(i) ~~th~~ Fluid passes past a solid wall, solid soluble in fluid

(ii) Flow rate is small.

$\therefore$ By Fick's 2nd law for steady state,

$$\frac{d^2 C_A}{dz^2} = 0$$

$\therefore C_A = C_{As} + (C_{Ae} - C_{As}) \frac{x}{\delta}$

$\therefore \frac{\partial C_A}{\partial x} = (C_{Ae} - C_{As}) \frac{1}{\delta}$

$\therefore k (C_{Ae} - C_{As}) = \frac{D_{AB}}{\delta} (C_{Ae} - C_{As})$

$\therefore \boxed{MTC = k = \frac{D_{AB}}{\delta}}$

1.6. The dimensionless nos. relating heat and mass transfer analogies are

Nusselt No. → Sherwood No.
(Nu → Sh)

Prandtl No. → Schmidt No.
(Pr → Sc)

$Nu = \frac{hL}{k}$ — h: H.T. coeff, k: Diffusivity

$Sh = \frac{k_c L}{D_v}$ — k_c: M.T. coeff, D_v: Diffusivity

$Pr = \frac{c_p \mu}{k}$ $\qquad Sc = \frac{\mu}{\rho D}$

2.7. Reynold's analogy

Reynold's proposed

$St_H = St_M \rightarrow$ Stanton no. (heat and mass)

i.e. $\frac{Nu}{Re\,Pr} = \frac{Sh}{Re\,Sc} = \frac{f}{2}$ → friction factor

Chilton Coldburn Analogy

Colburn factor (Colburn replace analogy in St_m by J_D)

$J_D = St_m\, Sc^{2/3}$

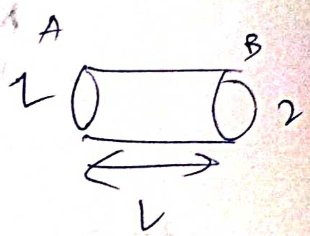
$J_H = St_H\, Pr^{2/3}$

$\therefore \; J_D = J_H$

$\Rightarrow \frac{Nu}{Re\,Pr} Pr^{2/3} = \frac{Sh}{Re\,Sc} Sc^{2/3}$

$\therefore \frac{Nu}{Re\,Pr^{1/3}} = \frac{Sh}{Re\,Sc^{1/3}} \quad (= 0.023\, Re^{-0.2})$

2.8. a) A in non diffusing B:

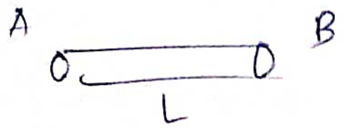


$N_A = \frac{D_{AB}\, dC_A}{dz} + \frac{N_A C_A}{C}$

$\therefore N_A = \cancel{\frac{D_{AB}}{z}} \cancel{C_A C} \quad \frac{D_{AB}}{z} c \ln\left(\frac{C - C_{A_2}}{C - C_{A_1}}\right)$

$$\boxed{\therefore M T_C = \frac{N_A}{C_{A_2} - C_{A_1}} = \cancel{\frac{D_{AB}}{l}} \quad \frac{D_{AB}\, c \ln\left(\frac{C - C_{A_2}}{C - C_{A_1}}\right)}{l\,(C_{A_2} - C_{A_1})}}$$

b) **Equimolar counter diffusion:**



$$N_A = D_{AB}\frac{dC_A}{dx} + 0 = D_{AB}\underbrace{\frac{\Delta C_A}{\Delta x}}$$

↳ as it is unif. with x, so derivative is replaced by finite difference

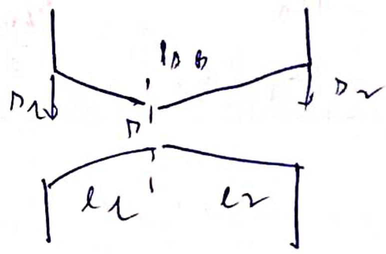
$$= D_{AB}\frac{(C_{A2} - C_{A1})}{l},$$

$$\therefore \boxed{MTC = \frac{N_A}{C_{A2} - C_{A1}} = \frac{D_{AB}}{l}}$$

Section 2

2.18. Diffusion through converging diverging region:

We can assume it to be two tapered tubes, for which result is known



Equimolar counter diffusion

$$n = \frac{\pi D_{AB}}{RT} \frac{r_1 r'}{l_1} (p_{A1} - p_{AB})$$

$$= \frac{\pi D_{AB}}{RT} \frac{r_2 r'}{l_2} (p_{AB} - p_{A2})$$

$\therefore$ p_{AB} :

$$\frac{r_1}{l_1}(p_{A1} - p_{AB}) = \frac{r_2}{l_2}(p_{AB} - p_{A2})$$

$$\therefore \quad p_{AB} = \frac{\frac{r_1}{l_1} p_{A1} + \frac{r_2}{l_2} p_{A2}}{\frac{r_1}{l_1} + \frac{r_2}{l_2}}$$

$$= \frac{r_1 p_{A1} l_2 + r_2 p_{A2} l_1}{r_1 l_2 + r_2 l_1}$$

$= 0.0375$ bar

(after putting values)

Now, $\left[\frac{dp_B}{dz}\right]$ $\left.\frac{dp_B}{dz}\right|_{neck} = -\left.\frac{dp_A}{dz}\right|_{neck} = \frac{W}{\pi r^2} \frac{RT}{D_{AB}}$

&

Rate of M.T.

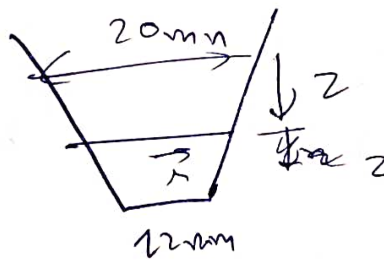
$$W = \frac{\pi D_{AB}}{RT} \frac{r_1 r_2 r}{r_1 l_2 + r_2 l_1} (p_{A1} - p_{A2})$$

$$= \cancel{6 \times 10} \; 6.57 \times 10^{-6}$$

$$\therefore \left.\frac{dp_B}{dz}\right|_{neck} = \frac{W}{\pi r^2} \frac{RT}{D_{AB}}$$

$$= \cancel{48} \; 0.18 \text{ bar/m}$$

2.17.



$\pi r^2 N_A = W$ (say)

$$N_A = \frac{D_{AB} P}{RT (P - p_A)} \frac{dp_A}{dz}, \quad r = r_1 - \frac{r_1 - r_2}{L} z$$

$$\therefore \frac{\pi D_{AB} P}{RT} \int_0^{p_A} \frac{dp_A}{P - p_A} = W \int_0^z \frac{dz}{\left(r_1 - (r_1 - r_2)\frac{z}{L}\right)^2}$$

$$\therefore W = \frac{\pi D_{AB} P}{RT} \frac{r_2}{z} \left[r_1 - (r_1 - r_2)\frac{z}{L}\right] \ln \frac{P}{P - p_{AV}}$$

$i.2$ Initial vaporization losses

$l_2 = 7.5\,cm = \frac{15}{2}\,cm \rightarrow$ half filled)

$W = 1.58 \times 10^{-10}$ kmol/s

c.4) Now, by mol balance,

$\cancel{-N_A A \frac{dN}{dt} = W = \pi r^2 \frac{dz}{dt} \rho_A}$

$$A \frac{dz}{dt} \frac{\rho_A}{M_A} = W$$

$$\therefore W = \pi r^2 \frac{dz}{dt}$$

$$= \pi \left(r_1 - (r_1 - r_2) z\right)^2 \frac{dz}{dt}$$

$$\therefore \int_{z_1}^{z_2} z\left[r_1 - \frac{r_1 - r_2}{2} z\right] dz = \frac{D_{AB} M_A}{\rho_A} \ln\left(\frac{P}{P - P_A}\right) t$$

Putting

$$\Rightarrow \left[z r_1 - \left[\frac{r_1 - r_2}{2}\right] \frac{z^2}{2}\right]_{z_1}^{z_2}$$

$$= \left[(z_1 - z_2) - \frac{(r_1 - r_2)}{L} \frac{(z_1 - z_2)(z_1 + z_2)}{2}\right]_{z_1}^{z_2}$$

$$= \cancel{(z_1 - z_2)} \left[L - (r_1 - r_2)\frac{(z_1 + z_2)}{2}\right]$$

$$= \frac{D_{AB}}{\rho_A} M_A \ln\left(\frac{P}{P - P_A}\right) t$$

Putting in values, we have

$t = 79\ h$

2.14. Diffusion from sphere: we use formula derived in Section 1:

$$t' = \frac{RT\rho_A R_0^2}{2 D_{AB}\, P M_A \ln\left[\frac{P - P_{A\infty}}{P - P_{AS}}\right]}$$

$P_{A\infty} = 0$, $P_{AS} = 0.8651$ mm Hg

$P = 13.6$ mm Hg

$D_{AB} = 0.0502 \times 10^{-4}$

$r_{c0} = 0.943 \times 10^{-2}$, $m = 29$

$\therefore\ t' = 229.5\ h$ (after putting values)

2.15. Diffusion from cylinder: we use formula derived in Section 1:

$$t = \frac{\frac{1}{2} r_{c1}^2 \ln\left(1 + \frac{\delta}{r_{c1}}\right) - \frac{1}{2} r_{c2}^2 \ln\left(1 + \frac{\delta}{r_{c2}}\right) + \frac{\delta}{2}\left[(r_{c1} - r_{c2}) - \delta \ln\left(\frac{r_{c1}+\delta}{r_{c2}+\delta}\right)\right]}{\frac{D_{AB} P}{RT} \frac{M_A}{\rho_A} \ln\left(\frac{P}{P - P_{AS}}\right)}$$

$= 10.35\ h$ (after putting values)

~~Q7~~ 3.2. Given, $Sh = 2 + 0.6 \, Re^{0.5} \, Sc^{0.33}$

$Re = \frac{(2r)\rho v}{\mu} = 5.73 \times 10^{9} r$

char. length

$Sc = \frac{\mu}{\rho D_{AB}} = \frac{1.92 \times 10^{5}}{1.2 \times 6.92 \times 10^{-6}} = 2.522$

$\therefore Sh = 2 + 0.6 (5.73 \times 10^{5} r)^{0.5} (2.522)^{0.3}$

$= 2 + 618 \sqrt{r}$ — (i)

Given, $T = 318\,K$, & also since $P_A << P$,

$\therefore \frac{P}{P - P_A} \sim 1$.

$\therefore Sh = \frac{k_G P_{Bm} RT(2r)}{P D_{AB}} = \frac{k_G (0.08317)(318)(2r)}{6.92 \times 10^{-6}}$

$= 7.641 \times 10^{6} k_G r$ — (ii)

$\therefore$ ~~$k_G =$~~ solving these we have

$k_G = \frac{2.616 \times 10^{-7}}{r} + \frac{8.085 \times 10^{-5}}{\sqrt{r}}$

$\therefore \frac{d}{dt} N_A = k_G \, \delta P$

$\therefore$ ~~dN_A~~ $N_A (4\pi r^2) = \frac{d}{dt} \frac{4}{3}\pi r^3 \frac{\rho}{M}$

$\therefore \dfrac{\left(\left(\dfrac{2.613 \times 10^{-7}}{r} \right) + \left(\dfrac{8.085 \times 10^{-9}}{\sqrt{r}} \right) \right)}{\cancel{(4\pi r^2)}}^{2}$

$= \frac{d}{dt} \frac{4\pi r^2}{2} \frac{\rho}{M} \frac{dr}{dt}$

$\therefore -\frac{dr}{dt} = \left(\frac{2.28}{1140} \right)^{TMR} \left(\frac{2.616 \times 10^{-7}}{r} + \frac{8.085 \times 10^{-9}}{\sqrt{r}} \right)$

(0.0011153)

$= \frac{3.39}{r} \times 10^{-12} + \frac{1.05}{\sqrt{r}} \times 10^{-8}$

$\therefore t = -\int_{0.005}^{0.025} \frac{dr}{\frac{3.39}{r} \times 10^{-11} + \frac{1.05}{\sqrt{r}} \times 10^{-8}}$

$= 3.84 \, h$

3.4. Let at time t, undissolved solid m

m

Tm,,

dissolved → 20-m

C for 1 201

$d_i = 0.6$ mm, $n_{particles} = 6.574\times10^{7}$

$\therefore m(t) = \frac{m}{6.57\times10^{7}}$

Instantaneous diameter

$$d_p = \left(\frac{6}{4\pi}\frac{m}{e}\right)^{\frac{1}{3}}$$

$$= 2.21\times10^{-4}\,m^{\frac{1}{3}}$$

Area $= \pi d_p^2$ t,

Total area $a = 10.1\,m^{\frac{2}{3}}$

$$\therefore Re_n = \frac{N d_p^2 e}{\mu}$$

$$Sh = 2 + 0.04\,Re^{0.504}\,Sc^{0.359}$$

$$= 2 + 0.44 \times \left(0.0\;3976\times m^{\frac{2}{3}}\right)^{0.504}\;653^{0.385}$$

$$= 2 + 1.67\,m^{0.336}$$

$$= \frac{k_L d_p}{D}$$

$\therefore\ k_L = 6.784 \times 10^{-6} \ (2 + 1.67\, m^{0.08})\ m^{-\frac{1}{3}}$

$\therefore$ rate of dissolution can be written as

$$-\frac{dm}{dt} = k_L\, a\, (c_s - c) \quad (= N_A\, a)$$

$$= (6.78 \times 10^{-6})(2 + 1.67\, m^{0.330})\, m^{-\frac{1}{3}} \left[10.1\, m^{\frac{2}{3}}\right] \left[80 - \frac{(20-m)(1000)}{520-m}\right]$$

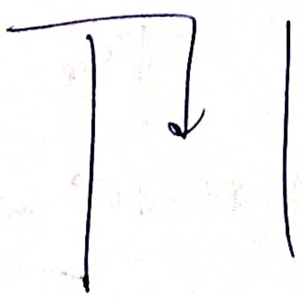
$$\therefore\ t = \int_0^{20} \frac{dm}{10.1 (6.78 \times 10^{-6})(2 + 1.67\, m^{0.330}) (m^{\frac{1}{3}}) \left[80 - \frac{(20-m)(1000)}{520-m}\right]}$$

$$= \underline{\underline{25 \text{ min}}}$$

3.5 We use penetration theory, due to the unsteady ~~state~~ stat(e) of the MT process.

$r \rightarrow$ radius of jet $\quad v \rightarrow$ velocity of jet

Q



$M_{H_2S} = 34$

$$K_L = 2\sqrt{\frac{D_{AB}}{\pi t_c}} = 2\sqrt{\frac{D_{AB}}{\pi}\left(\frac{v}{l}\right)}$$

$$\& \quad l_s \cdot t_c = l$$

Now, rate of absorption of H_2S

$$= N_A \times 2\pi r l$$

$$= 2\pi r L \, k_L \,(C_{Ai} - C_{Ab})$$

$$C_{Ai} = 1.03 \times 0.1136 = 0.117$$

$C_{Ab} = 0$ (bulk does not contain H_2S)

$$\therefore \quad \underbrace{4.42 \times 10^{-4}\ g/s}_{\downarrow \text{ mol/s}} = 2\pi l \, k_L \,(C_{Ai} - C_{Ab}) \times M_{H_2S}$$

$$\therefore \quad 1.3 \times 10^{-8} = 2\pi l \underbrace{\sqrt{\frac{Q}{\pi v}}}_{} \; 2\sqrt{\frac{D_{AB} v}{\pi l}} \underbrace{(0.117 - 0)}_{C_{Ai} - C_{Ab}}$$

$$\& \quad \pi r^2 v = Q$$

$$\therefore r = \sqrt{\frac{Q}{\pi v}}$$

$$= 4\sqrt{D_{AB}} \; 1.32 \times 10^{-5} \,(0.05)(0.117)$$

$$\therefore \boxed{D_{AB} = 1.17 \times 10^{-9}\ m^2/s}$$

3.6. ~~We use Penetration theory but also~~

Contact ~~Residence~~ time, we use Penetration Theory

$$t_c = \frac{d_b}{v_b} = \frac{1 cm}{20 \ cm/s} = 0.05 \ cm/s$$

MTC $\quad k_L = 2\left(\frac{D_{AB}}{\pi t_c}\right)^{\frac{1}{2}} = 0.0236 \ cm/s$

Residence time of single bubble $= \frac{0.3 \ m}{0.2 \ m} = 1.5 s$

Volume $= 0.5236 \ cm^3$,

~~Area~~ $= 3.1416 \ cm^2$

~~Volume = 0.~~

$C_s \ \cancel{g_{CO_2}} = 2.493 \times 10^{-5} \ gmol/cm^3$

($P_{CO_2} \sim 0.5 atm$),

So by Henry's Law

we have ~~H = 0~~ m/s

~~H = 1.67 × 10^8 Pa~~

~~C_b~~ $\quad C_b = 0$ $\quad H = 1640$)

Amount of CO_2 absorbed from a single bubble in 1.5s

$= \cancel{A} \ k_L \ 4\pi r^2 (C_s - C_b) t$

$= 2.66 \times 10^{-6}$

∴ Avg. no. of bubbles formed $= \frac{15}{0.5236}$

$= 28.65 \ /min$

∴ Rate of absorption of CO_2

$= 1.66 \times 10^{-6}$ gmol/ bubble $\times 28.65$ bubble/min

$= \boxed{4.75 \times 10^{-5} \text{ gmol/min}}$

3.7. (Gas absorbed in an agitated vessel)

Henry's Law for CO_2

$p_{CO_2} = 1640\, x^*$

∴ For $p = 2$ atm,

$x^* = 0.00122$

Molecular weight of solution $= M_1 x^* + M_2 (1 - x^*)$

$= 44 \times 0.00122 + 28 \times 0.99878$

$= 18.03$

~ 18

Moles of soln. /m³ $= \frac{997}{18} = 55.4$

Moles of CO_2 /m³ soln $= \cancel{55.4} \quad 55.4 \times 0.00122$

$= 0.0676$

Conc. of carbonate soln. leaving vessel $= \frac{2.3}{44} = 0.0523$

Inlet water $\rightarrow$ $p_{CO_2} = 0$

$\therefore$ At steady state,

rate of MT = $\frac{1.667 \times 10^{-5}}{0.0523}$ $\rightarrow Q$

$= 8.729 \times 10^{-7}$ $= 1 L/min$

$= 1.677 \times 10^{-5}$ m^3/s

$\therefore$ ~~rate of absorption~~

$= N_A A$

$= k_L \Delta C A$

$\therefore$ $k_L \times (0.076 - 0.0523)(0.0087)(80)$

$= 8.729 \times 10^{-7}$

$\therefore k_L = 8.903 \times 10^{-5}$ m/s

(a) Film Theory approach, ~~film~~,

$$\delta = \frac{D_{AB}}{k_L} = \frac{1.92 \times 10^{-9}}{8.903 \times 10^{-5}}$$

$= 0.02$ mm

(b) Penetration Theory approach 4,

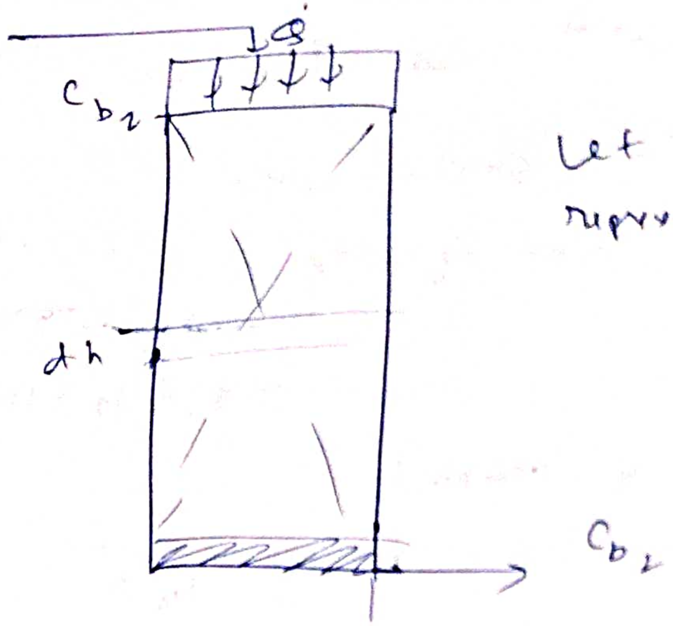
$$t_c = \frac{4 D_{AB}}{\pi k_L^2} = \frac{4 \times 1.92 \times 10^{-9}}{\pi (8.903 \times 10^{-5})^2}$$

$= 0.3085$

(c) Surface renewal theory 4, ~~rate of~~ approach

$$s = \frac{k_L^2}{D_{AB}} = \frac{(8.903 \times 10^{-5})^2}{1.92 \times 10^{-9}} = 4.13\ s^{-1}$$

3.8.



Let $C_b(x)$ represent conc. of

Mole balance equation:

rate of MT $= \frac{dn_A}{dt}\Big|_h$ (steady state, so no accumulation)

$$\therefore \underbrace{(k_L \bar{a})}_{\text{MTC}} \underbrace{A\,dh}_{\text{diff. volume}}(C_s - C_b) = \frac{dn_A}{dt}$$

Mass transfer rate per volume

$$\therefore (k_L \bar{a})\, A\,dh\,(C_s - C_b) = Q\,dC_b$$

$$\therefore \frac{dC_b}{C_s - C_b} = k_L \bar{a}\, \frac{A\,dh}{Q}$$

$$\therefore \ln\left(\frac{C_s - C_{b1}}{C_s - C_{b2}}\right) = k_L \bar{a}\, \frac{Ah}{Q} \quad (1)$$

We use correlation

$$\varepsilon j_D = 0.25\, Re^{-0.32}$$

$\longrightarrow$ Reynold's no.

$\hookrightarrow$ Colburn factor

$\hookrightarrow$ voidage

$$Re = \frac{0.8 \times 2.2}{0.0009} = 185, \quad Sc = \frac{\nu}{D_{AB}} = 990$$

$$\therefore \varepsilon j_D = \varepsilon \frac{Sh}{Re\, Sc^{1/3}} = 0.25\,(185)^{-0.32}$$

$$= 0.0405$$

$$\therefore Sh = \frac{0.0405 \times 185 \times (990)^{1/3}}{0.4}$$

$$= 229$$

$$\therefore k_L = Sh \frac{D_{AB}}{d_p} = 225 \frac{10^{-5}}{0.8}$$

$$= 0.00281 \text{ cm/s}$$

$$\therefore \bar{a} = \frac{6(1-\varepsilon)}{d_p} = \frac{6(1-0.4)}{0.8} = 4.5 \text{ cm}^2/\text{cm}^3$$

$\hookrightarrow$ interficial area of

an reqd

Putting this in (1), we have

$$C_{b_2} = 1 \text{ kg/m}^3$$

Example 3.9 .

$\to$ ~~solute free base~~ gas molar gas flow rate

$$-\underbrace{G\,dy} = \underbrace{\pi d\, dz\ \overbrace{k_y(y-y_i)}}$$

$\to$ MT rate

by mass balance

diff volume

of volume flow rate

$\times$ diff conc.

= net molar flow rate of component.

$$\therefore \int \frac{dy}{y-y_i} = -\int \frac{\pi d\, k_y}{G}\, dz$$

$$\therefore \ln\frac{y_1}{y_2}\quad k_y = \frac{G \ln(y_1/y_2)}{\pi d L}$$

G ~~calc~~

~~Avg~~ M_{gas} = ~~mole~~ $0.02(78) + 0.98(28)$

$= 29$

At top $\Rightarrow 28.2$ (air)

~~At bott~~ Avg molar gas flow rate

$= \frac{13500}{29} = 465.5$ kmol/m²h

At top $\rightarrow$ 458.6 kmol/m²h

Avg $\rightarrow$ ~~458~~ $\frac{1}{2}$ (bottom + top) = 462 kmol/m²h

Area of cross section $= \pi (0.035 \times 10^{-2} m)^2$

$= 9.62 \times 10^{-4}$

$\therefore G = vA = 9.62 \times 10^{-4} \times 462$

$= 0.4448$ kmol/h

$k_y = 1.786$ kmol/h m² Δy

$\hookrightarrow y_2 - y_1$

let N_2-benzene system be 1,

air-NH_3 system be 2.

Thus,

$Re_1 = 7140$, $Re_2 = 8630$,

$Sc_1 = 2.5$, $Sc_2 = 0.675$

$\therefore \frac{J_{D1}}{J_{D2}} = \left(\frac{Re_1}{Re_2}\right)^{-0.23}$

$\rightarrow \frac{Sh_1}{Sh_2} = \left(\frac{Re_1}{Re_2}\right)^{0.77} \left(\frac{Sc_1}{Sc_2}\right)^{0.33}$

Taking $P_{BM} = P$ in Sh, we have

$Ky_2 = 4.25$ kmol/h m² Δy in air-NH_3 system.

Treybal

3 - 4. ~~What~~

Given,

$$\frac{C_{Ai} - C_{AL}}{C_{Ai} - C_{A0}} = 0.7857\, e^{-5.1213\eta} + 0.1001\, e^{-39.3\eta} + 0.03599\, e^{-105.64\eta} + \dots n$$

For MT,

$$\eta = \frac{2 D_{AB} L}{3 \delta^2 u_y} = \frac{2}{3 Pe_D} \frac{L}{\delta}$$

~~[illegible]~~

For ~~mass~~ heat transfer, it is replaced by

$$\eta = \frac{2}{3 Pe_H} \frac{L}{\delta} = \frac{2 \alpha L}{3 \delta^2 u_y}$$

And

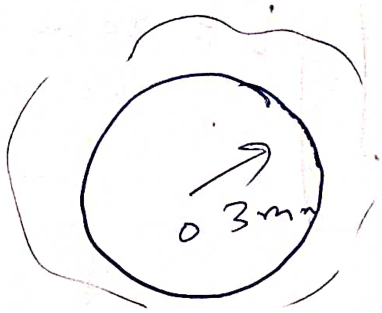
$$\frac{C_{Ai} - C_{AL}}{C_{Ai} - C_{A0}}$$ be replaced with

$$\frac{t_i - t_L}{t_i - t_0}.$$

This form the analogous relation.

Section 3

3.1.



We use the spherical geometry MT formula we derived in section 1:

$$\frac{dm}{dt} = W = N_A \times 4\pi r^2$$

$$= \frac{4\pi D_{AB}}{\bar{R}T} P r_s \ln\left(\frac{P - P_{A\infty}}{P - P_{As}}\right) M_A$$

Here, $r_s = 0.3mm$,

$P_\infty = 0$, $P_{As} = 0.559$ mm Hg

$P = 13.6$ cm Hg.

$$\therefore \frac{dm}{dt} = \frac{4 \times \pi \times 6.92 \times 10^{-6} \, 1.01(10^5)(0.0003) \ln\left(\frac{13.6}{13.6 - 0.559}\right)}{8.314 \times 318}$$

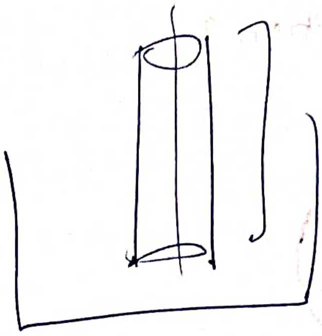
$$\times \underbrace{0.128 \text{ kg/mol}}, \rightarrow M \text{ nepthalan}$$

$$= 4.152 \times 10^{-8} \text{ kg/s} \quad \times 0.128$$

$$5.31 \times 10^{-9} \text{ kg/s}$$

$= \cancel{4.152}$

3.2.



(a) ~~dco2~~ We use equation derived in Section 1 for cylindrical system:

$$\frac{d n_{CO_2}}{dt} = \frac{2\pi D_{AB} P L}{RT \ln\left(1+\frac{\delta}{r_c}\right)} \ln\left(\frac{P - P_A}{P - P_{AS}}\right)$$

$$= \frac{2\pi \times 10^{-5} \times 1.01 \times 10^5 (0.2)}{8.314 \times 1145 \ln\left(1+\frac{1-0.5}{0.5}\right)} \ln\left(\frac{1-0}{1}\right.$$

$r = \frac{1}{2} = 0.5$,

$r + \delta = r_{40\%} = 1$

$\therefore$ $\delta = 1 - 0.5 = 0$

$= -9.83 \times 10^{-5}$ mol/s

(b) ~~cp~~ $P = 1.01 \times 10^5 \times 0.4$ Pa

$= 0.4$ atm

$\therefore y_{O_2} = \frac{0.4}{1} = 0.4$

3.3.

0.2

(a) $Re_L = \frac{\rho v L}{\mu} = \frac{vL}{\nu} = \frac{20\times 0.2}{1.5\times 10^{-5}}$

$= 2.667\times 10^{5}$

$Pr \equiv Sc = \frac{\nu}{D_{AB}} = \frac{1.5\times 10^{-5}}{6\times 10^{-6}}$

$= 2.5$

$Nu = 0.664\, Re^{\frac{1}{2}}\, Pr^{\frac{1}{3}}$

∴ By Colburn Analogy,

$Sh = 0.664\, Re^{\frac{1}{2}}\, Sc^{\frac{1}{3}}$

$= \frac{\overset{\text{MTC}}{k_c} L}{D_{AB}}$

∴ $k_c = \frac{D_{AB}}{L}\left(0.664\, Re^{\frac{1}{2}}\, Sc^{\frac{1}{3}}\right)$

$= \frac{6\times 10^{-6}}{0.2}(0.664)(2.667\times 10^{5})^{\frac{1}{2}}(2.5)^{\frac{1}{3}}$

∴ $\boxed{k_c = 0.01396\ m/s}$

(b) rate of MT

per unit width $= \frac{M_a \times A \times k_c \Delta C}{W}$ ↳ width

$= M_A \times L \times k_c \Delta c$

$(A = Lw)$

$= 0.128 \text{ kg/mol} \times 0.2 \text{ m}$

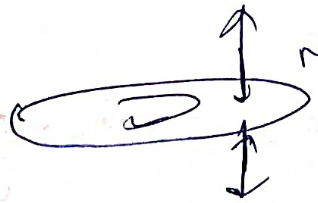
$\times 0.01396 \text{ m/s} \times (10^{-5} \times 10^{3} - 0)$

mol / m³

calculating

$\therefore$ $\boxed{\text{rate of MT per unit width} = 3.57 \times 10^{-6} \text{ kg / ms}}$

3 . a .



Rate of dissolution $= \underbrace{k_L \Delta C}_{\text{mass flux}} \underbrace{\left((2) \times \pi \frac{D^2}{4}\right)}_{\text{area}}$

For k_L, we use

$$Sh = 0.62\, Re^{\frac{1}{2}}\, Sc^{\frac{1}{3}}$$

Here,

$$Re = \frac{D^2 \omega \rho}{\mu}$$

$$= \frac{0.03^2 \left(\frac{20}{60} \times 2\pi\right)(10^3)}{10^{-3}}$$

10^{-3} is of water

$$= 1884.956$$

Given, $D_{AB} = 10^{-5} cm^2/s = 10^{-5} \times 10^{-4}\ m^2/s$

$$\therefore Sc = \frac{\mu}{\rho D_{AB}} = \frac{10^{-3}}{10^3(10^{-5} \times 10^{-4})}$$

$$= 1000$$

$\therefore \quad Sh = 0.62\,(1884.956)^{\frac{1}{2}}\,(1000)^{\frac{1}{3}}$

$= 269.179$

$= \cancel{\frac{K_L}{D_{AB}}} \quad \frac{K\,D}{D_{AB}}$ → Diameter

$\therefore \quad \frac{K_L\,(0.03)}{10^{-9}} = 269.179$

$\therefore \quad K_L = 8.97 \times 10^{-6}$ m/s

$\therefore$ Rate of dissolution

$= 2\,K_L\,\Delta C\,\frac{\pi D^2}{4}$

$= \frac{K_L\,\Delta C\,\pi D^2}{2}$

$= 8.97 \times 10^{-6} \times \left(0.003 \times \frac{10^{-3}}{10^{-9}} - 0\right) \times \pi \times \frac{0.03^2}{2}$

conc. of benzoic acid in water is 0 as very large volume of water

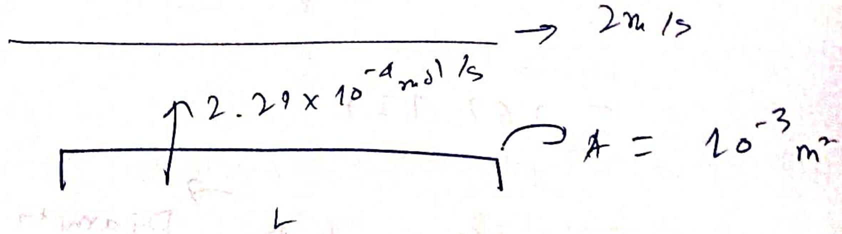
$= 1.22 \times 10^{-5}$ mol/s

In molar mass term,

$\frac{dm}{dt} = 1.22 \times 10^{-5} \times \frac{122}{10^3}$ kg/s

$= 1.477 \times 10^{-6}$ kg/s

3.5.



We again use

$$Sh = \cancel{0.662}\ 0.662\, Re^{\frac{1}{2}} Sc^{\frac{1}{3}}$$

~~As~~ ~~Re = 2x~~

~~Let length of slab be~~

~~Let~~

Let us assume it to be a square slab.

then,

~~ar~~ $L = 10^{-\frac{3}{2}}\ m = 0.0316\ m$

$$\therefore \quad Re = \frac{vL}{\nu} = \frac{2 \times 0.0316}{1.55 \times 10^{-5}}$$

$$= 4077.41$$

$$Sc = \frac{\nu}{D_{AB}} = \frac{1.59 \times 10^{-5}}{1.5 \times 10^{-5}}$$

$$= 1.033$$

$\therefore Sh = 0.662 \times 4077.41^{\frac{1}{2}} \times 1.033^{\frac{1}{3}}$

$= 42.73$

$Sh = \frac{k_c L}{D_{ab}}$

$= \frac{k_c \times 0.0316}{1.5 \times 10^{-5}}$

$\therefore k_c = \frac{1.5 \times 10^{-5}}{0.0316} \times 42.73$

$\therefore k_c = 0.02 \, m/s$

3.6 For ~~heat~~ Mass Transfer,

we replace Nu by Sh, → Sherwood no.

Pr by Sc. → Schmidt no.

→ Sherwood ratio.

$\therefore Sh = 0.023 Re^{0.8} Sc^{\frac{1}{3}}$

$\Rightarrow$ $\boxed{\frac{kD}{D_{AB}} = 0.023 Re^{0.8} Sc^{\frac{1}{3}} \quad = Sh}$

3.7.

$$D_{AB}\Big|_{300K} = 1.5 \times 10^{-9}\ m^2/s$$

$$Sc = \cancel{\mu}\ \frac{\nu}{D_{AB}}$$

(a) 300K, 1atm

$\cancel{\rho_A}$ $\cancel{D_{O_2}}$ 1atm

From literature,

$$D_{oxygen, air}\Big|_{293K} = 0.219\ cm^2/s$$

$$\therefore D_{oxygen, air}\Big|_{300K} = 0.219 \times \left(\frac{300}{293}\right)^{\frac{7}{4}}$$

(by Fuller Correlation)

$$= 0.228\ cm^2/s$$

$$= 2.28 \times 10^{-5}\ m^2/s$$

$\mu_{air} = 0.0186$ m Pas $= \cancel{a}\ 1.86 \times 10^{-5}$ Pas

(from literature) $\rho \sim 1.225$ kg / m^3

$\therefore$ ~~Sc~~

$$Sc = \frac{1.86 \times 10^{-5}}{1.225 \times 2.28 \times 10^{-5}}$$

$$= 0.666$$

(b) 300 K, water

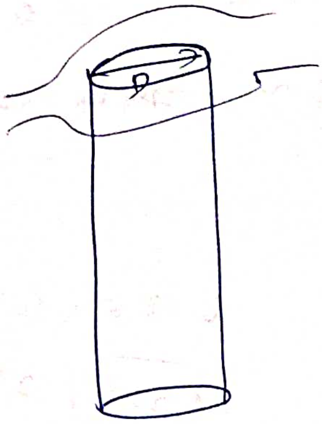
~~$\mu \approx 0.001\ m^2/.$~~

$$\nu = \frac{\mu}{\rho} = \frac{0.002}{10^3} = 10^{-6}\ m^2/s$$

$$D_{AB} = 1.5 \times 10^{-9}\ m^2/s$$

$$\therefore \quad Sc = \frac{10^{-6}}{1.5 \times 10^{-9}} = 666.667$$

3.8



$$Nu = 0.43 + 0.532\, Re^{0.5}\, Pr^{0.31}$$

~~Heat~~ Heat transfr

$\hookrightarrow$ $Re = \frac{\rho D v}{\mu} = \frac{D v}{\nu}$

$= \frac{0.028}{\nu}$

$Pr = \cancel{\frac{\mu c_p}{k}}\ \frac{\nu}{\alpha}$

$\therefore\ Nu = 0.43 + 0.532 \times \left(\frac{0.028}{\nu}\right)^{\frac{1}{2}} \left(\frac{\nu}{\alpha}\right)^{0.31}$

$= 0.43 + 0.071\ \frac{\nu^{-0.19}}{\alpha^{0.31}}$

$= \cancel{\frac{hL}{k}}\ \frac{hD}{k}$

$\therefore\ h = \left(0.43 + \frac{0.071}{\nu^{0.19}\alpha^{0.31}}\right) \frac{k}{0.006}$

$= \left(7.167 + \frac{11.83}{\nu^{0.19}\alpha^{0.31}}\right) k$

$\therefore$ ~~ΔQ~~

$$\dot{Q} = a\,h\,\Delta T = \frac{4}{3}\pi r^3 \times \left(7.267 + \frac{11.83}{v^{0.19}\alpha^{0.31}}\right) K\,(60-83)$$

~~HTC~~ Heat Transmission

$$= 6.4\times10^{-9}\left(7.267 + \frac{11.83}{v^{0.19}\alpha^{0.31}}\right) K$$

~~$= 4.59 + 7.57\times10^{-3}$~~

$$= \left(4.59 + \frac{7.57}{v^{0.19}\alpha^{0.31}}\right)\times10^{-3}\,K$$

Now, by calorimetry,

$$\dot{Q} = \cancel{H_A}\ H_{UF_6}\,\dot{m}$$

specific heat of sublimation

$$= H\,\dot{m} \quad (H = H_{UF_6})$$

$$\therefore \boxed{\dot{m} = \frac{\dot{Q}}{H} = \frac{\left(4.59 + \frac{7.57}{v^{0.19}\alpha^{0.31}}\right)(10^{-3}K)}{H}}$$