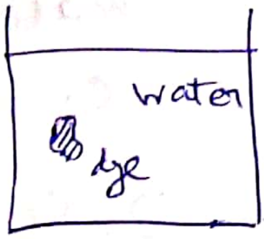
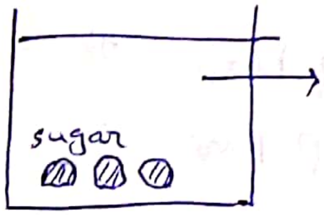
1. Tea leaves → Tea
2. Distillation Colum
3. Centrifugation

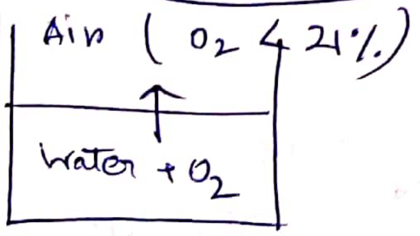
} Mechanical / Physical

4. 

Conc. diff.

5. 

6. A + Acetone | Acetic Acid

7. 

8. Osmosic

} Driving force; Chemical Potential Difference

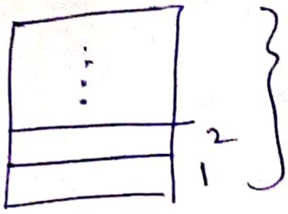
$$\mu_i = \left(\frac{\partial G}{\partial n_i}\right)_{n_j \neq i, T, P}$$

<u>Mass Transfer</u>: Movement of material due to difference in Chemical potential

<u>Molecular Diffusion</u>. Governed by the kinetic energy of the molecule.

<u>Eddy Diffusion</u>: Enhanced by external force (Creation of packets of fluid)

Mass Transfer → Diffusion
Mass Transfer → Convective MT



n components

Concentration

mass / vol

$$\rho_i = \frac{m_i}{V}$$

$$\sum \rho_i = \rho$$

$$\omega_i = \frac{\rho_i}{\rho}$$

$$\sum \omega_i = 1$$

mole / vol.

$$c_i = \frac{n_i}{V}$$

$$\sum c_i = c$$

Liq Phase: $x_i = \frac{c_i}{c}$

Vap phase: $y_i = \frac{c_i}{c}$

$$p_i = c_i RT$$

$$\therefore\ y_i = \frac{p_i}{P}$$

u_i = vel. of comp 'i'

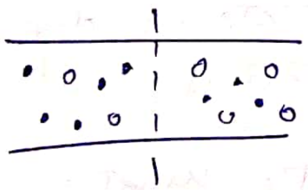
Average velocity

Mass

$$u = \frac{\sum \rho_i u_i}{\sum \rho_i}$$

Mole

$$U = \frac{\sum c_i u_i}{\sum c_i}$$



Reference frame

REF velocity $= 0$

$= u$

$= U$

Flux of component 'i'

Mass / Area Time of 'i'

- Ref v = 0: $n_i = \rho_i u_i$
- Ref v = U: $j_i = \rho_i (u_i - U)$
- Ref v = u: $i_i = \rho_i (u_i - u)$

Moles / Area Time of 'i'

- Ref v = 0: $N_i = c_i u_i$
- Ref v = U: $J_i = c_i (u_i - U)$
- Ref v = u: $J_i = c_i (u_i$ …

☆

Diffusive Flux $J_i = c_i(u_i - U) = c_i u_i - c_i U$

$= N_i$ — Convective Flux.

1. Def of MT: Seperation of material / molecules based on chemical potential

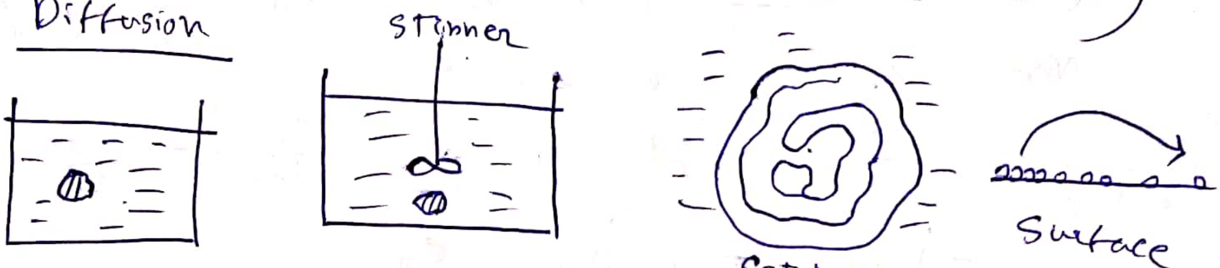
$N_i = J_i + c_i U$

Total flux · Diffusive Flux · Convective Flux

$$\boxed{N_i = J_i + \frac{c_i}{c}\left(\Sigma N_i\right)}$$

Binary System: $N_A = J_A + \frac{C_A}{c}(N_A + N_B)$

Diffusion



Molecular Diffusion · Eddy Diff · Catalyst · Surface Diffusion

Eddy Diff → Convective MT

Knudsen Diff (Pore Diff)

Flux $\propto$ Conc. gradient

$J_A \propto -\frac{dC_A}{dx}$

Ficks Law

$$\boxed{J_A = -D_{AB}\frac{dC_A}{dx}}$$

D_{AB} → Diffusivity / Diffusion Co-eff

☆ What are the factors D_{AB} depends on.

Unit of D_{AB}: m^2/s

$$\boxed{N_A - \frac{C_A}{C}(N_A + N_B) = -D_{AB}\frac{dC_A}{dx}}$$

$$\mu_i = \mu_i^0 + RT\ln(a_i)$$
$$= \mu_i^0 + RT\ln(\gamma_i C_i)$$

$$\frac{d\mu_i}{dx} = \frac{RT}{\cancel{\gamma_i} C_i}\cancel{\gamma_i}\frac{dC_i}{dx} \quad \therefore \frac{dC_i}{dx} = \frac{C_i}{RT}\frac{d\mu_i}{dx}$$

Proof: $D_{AB} = D_{BA}$

$$N_A - \frac{C_A}{C}(N_A + N_B) = -D_{AB}\frac{dC_A}{dx}$$
$$N_B - \frac{C_B}{C}(N_A + N_B) = -D_{BA}\frac{dC_B}{dx}$$

$$(N_A + N_B) - \frac{C_A + C_B}{C}(N_A + N_B) = -D_{AB}\frac{dC_A}{dx} - D_{BA}\frac{dC_B}{dx}$$

Now, $C_A + C_B = C = \text{Const}$

$$\therefore \frac{dC_A}{dx} + \frac{dC_B}{dx} = 0 \quad \therefore \frac{dC_B}{dx} = -\frac{dC_A}{dx}$$

$$\therefore -D_{AB}\frac{dC_A}{dx} + D_{BA}\frac{dC_A}{dx} = 0$$

$$\therefore \boxed{D_{AB} = D_{BA}}$$

1) $q = -k\frac{dT}{dx} = -\frac{k}{\rho C_p}\frac{d(\rho C_p T)}{dx}$

2) $\tau = -\mu\frac{dv}{dx} = -\alpha\frac{d(Q/V)}{dx}$

$$= -\frac{\mu}{\rho}\frac{d(\rho v)}{dx} = -\frac{\mu}{\rho}\frac{d(mv/V)}{dx}$$

3) $J_A = -D_{AB}\frac{dC_A}{dx} = -D_{AB}\frac{d(n_A/V)}{dx}$

$\alpha = \frac{k}{\rho C_p}$ = Thermal diffusivity

$\frac{\mu}{\rho} = \nu$ = momentum Diffusivity

D_{AB}

} Analogous (m^2/s)

Molecular Diffusivity

- Correlation
  - Gas Phase (non polar)
    - Based on Kinetic Theory
    - Hershfelder (or Chapman - Escag)
    - Fuller
  - Liq Phase
- Measurement

<u>Kinetic Theory</u> $D_{AA^*} = \frac{1}{3}\lambda u$

λ = mean free path $= \frac{KT}{\sqrt{2}\pi\sigma_A^2 P}$

$u = \sqrt{\frac{8KNT}{\pi M_A}}$

$\underline{D_{AA^*}} = \frac{1}{3}\frac{KT}{\sqrt{2}\pi\sigma_A^2 P}\sqrt{\frac{8KNT}{\pi M_A}} = \frac{2}{3}\frac{T^{3/2}}{\pi^{3/2}\sigma_A^2 P}\left(\frac{K^3 N}{M_A}\right)^{1/2}$

$= \frac{2}{3}\left(\frac{K}{\pi}\right)^{3/2}\frac{N^{1/2}T^{3/2}}{P\sigma_A^2}\left(\frac{1}{M_A}\right)^{1/2}$

$D_{AB} = \frac{2}{3}\left(\frac{K}{\pi}\right)^{3/2}\frac{N^{1/2}T^{3/2}}{P(\sigma_{AB})^2}\left(\frac{1}{2M_A}+\frac{1}{2M_B}\right)^{1/2}$

$\sigma_{AB} = \frac{\sigma_A+\sigma_B}{2}$

Value of D_{AB} (cm^2/s) $= \frac{0.001858\, T^{3/2}\left(\frac{1}{M_A}+\frac{1}{M_B}\right)^{1/2}}{P\sigma_{AB}^2\,\Omega_D}$

Hershfelder

24.07.2019

Transport Properties : Thermal Diffusivity $\left(\frac{k}{\rho C_p}\right)$
Mass " (D_{AB})
Momentum " (μ/ρ)

1. Analogy

2. D_{AA^+} =

Hirshfelder

$$D_{AB} = \frac{\frac{2}{3}\left(\frac{k}{\pi}\right)^{3/2} N^{1/2} T^{3/2}\left[\frac{1}{2M_A}+\frac{1}{2M_B}\right]^{1/2}}{P\left(\frac{\sigma_A+\sigma_B}{2}\right)^2 \Omega_D}$$

Ω_D — Lennerd Zones potential

$\Omega_D = f\left(\frac{RT}{\varepsilon_{AB}}\right)$

ε = Lennerd Zones parameter

$\varepsilon_{AB} = (\varepsilon_A \varepsilon_B)^{1/2}$

$\sigma = 1.18\, v_b^{1/3}$
$= 0.341\, v_c^{1/3}$
$= 2.44\, (T_c/P_c)^{1/3}$

v_b = molecular volume at boiling pt (usual)

$\varepsilon/K = 0.77\, T_c$
$= 1.15\, T_b$

Fuller :

$$D_{AB} = \frac{10^{-3}\, T^{1.75}\left[\frac{1}{M_A}+\frac{1}{M_B}\right]^{1/2}}{P\left[(\Sigma v)_A^{1/3}+(\Sigma v)_B^{1/3}\right]^2}$$

v = Atomic volume

Σv = Molecular vol.

Scanned by CamScanner

KT : $D_{AB} \propto T^{3/2}$

Hershfelder : $D_{AB} \propto T^{3/2} \frac{1}{\Omega_D}$

$\Omega_D = f\left(\frac{RT}{\varepsilon_{AB}}\right)$

Fuller : $D_{AB} \propto T^{1.75}$

$D_{AB} \propto \frac{1}{P}$

~~Platy #~~ $D_{1m} = \frac{1}{y_2'/D_{12} + y_3'/D_{13} \cdots \frac{y_n'}{D_{1n}}}$

$y_n' = \frac{y_n}{1-y_1}$

$D_{AB} = \frac{RT}{6\pi r \mu_B}$ Einstein - Stokes Law (based on hydrodynamic Theory)

Assumption Dilute soln

$\frac{D_{AB}\mu_B}{T} = \text{const.}$ μ_B = solvent viscosity

$\frac{D_{AB}\mu_B}{T} = f(V_B)$ ← Wilke Chang

$\frac{D_{AB}\mu_B}{T} = \frac{7.5 \times 10^{-3}}{V_A^{0.6}} (\phi_B M_B)^{1/2}$

V_A → $cm^3/gmol$

ϕ_B = association factor of the solvent

Hayduk Caudie

$D_{AB}^{0} = 13.26 \times 10^{-5} \mu_B^{-1.14} V^{-0.589}$

D_{AB}^0 → (infinitely dilute soln) (cm^2/s)

μ_B → cp

V → $cm^3/gmole$

$$D_{AB}\,\mu = \left(D^{0}_{BA}\,\mu_A\right)^{x_A}\left(D^{0}_{AB}\,\mu_B\right)^{x_B}\left[1 + \frac{d\ln\gamma_A}{d\ln x_A}\right)$$

25.07.2019

Estimation of Molecular diffusivity

Gas | Liq

$$D_{AB}\Big|_{T_2} = D_{AB}\Big|_{T_1}\,\frac{(\Omega_D)_{T_1}}{(\Omega)_{T_2}}\left(\frac{T_2}{T_1}\right)^{3/2}$$

$\lambda > d_{pore}$ ⇒ Knudsen Diffusion / Pore Diffusion

λ ⇒ Mean free Path

d_{pore} ⇒ Diameter of pore/ microchannel

K_n = Knudsen No. = $\dfrac{\lambda}{d_{pore}}$

$K_n > 1$ ⇒ Knudsen Diffusion

$K_n < 1$ ⇒ No " "

For Molecular Diffusion

$$J_A = -D_{AB}\frac{dC_A}{dx}$$

For Knudsen Diffusion

$$J_A = -\left(D_{KA}\frac{\epsilon}{\tau}\right)\frac{dC_A}{dx}$$

$$\rightarrow D_{KA}\frac{\epsilon}{\tau} = D^{eff}_{AK}$$

ϵ = porosity

τ = Torchuosity

For straight path, $\tau = 1$

$$D_{KA} = \frac{1}{3} d_{Pore} u \qquad u = \sqrt{\frac{8KNT}{\pi M_A}}$$

$$= 4850\, d_{pore} \sqrt{\frac{T}{M_A}}$$

In Case of Combination of Molecular Diffusion + Knudsen Diffusion (In case of high conc.)

$$J_A = - D_{Ae} \frac{\varepsilon}{\tau} \frac{dC_A}{dx}$$

$$\frac{1}{D_{Ae}} = \frac{1 - \alpha J_A}{D_{AB}} + \frac{1}{D_{KA}} \qquad \alpha = 1 + \frac{N_B}{N_A}$$

$J_A = 0$ or when $\alpha = 0$

$$\frac{1}{D_{Ae}} = \frac{1}{D_{AB}} + \frac{1}{D_{KA}}$$

Surface Diffusion :


surface

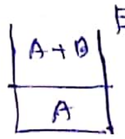
$$J_A = - D_{AS} \frac{dC_A}{dx}$$

for ~~egg~~ fashionable Product → 2-6 months

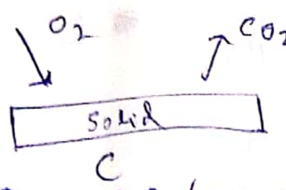
Binary Molecular Diffusion — 31.07.2017

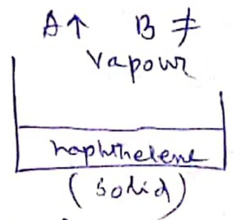
- A + B
- Steady state
- No reaction
- Single Phase Homogeneous
- Constant geometry

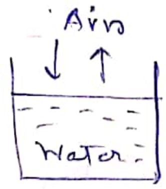
Ex. Naphthalene Sublimation
Charcol burning
Evaporation of water



$\boxed{A\uparrow \quad B \not\uparrow}$







A↑ − B↑ (Counter Diffusion)

Depletion / Accumulation rate is so slow, it is considered to be S.S.

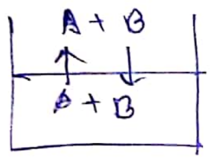
$$\frac{dN_A}{dx} = \frac{d\cancel{C_A}^{\,0}}{\cancel{dt}} = 0 \qquad \frac{dN_A}{dx} = 0$$

$$C + O_2 = CO_2$$
$$1 \qquad 1$$

$\boxed{\text{equimolar counter diffusion}}$

$$C + \tfrac{1}{2}O_2 = CO$$

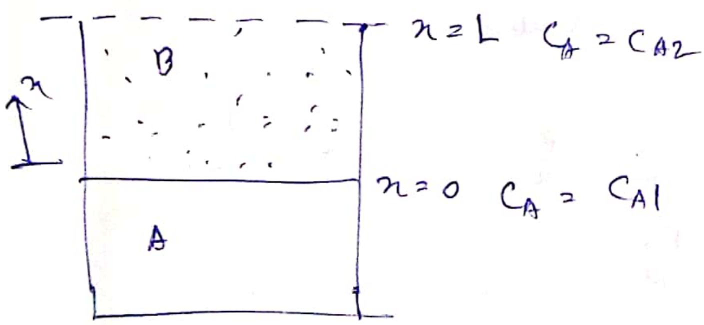
$\boxed{\text{Non-equimolar} \;\;\text{"}\;\;\;\; \text{"}}$



A↑ − B↑

$N_A L_A = N_B L_B$

Thermally Isolated



Case - A

A↑ , B ≠

$$\frac{dN_A}{dx} = 0$$

$$J_A = -D_{AB}\frac{dC_A}{dx}$$

$$N_A - \frac{C_A}{C}\left(N_A + \cancel{N_B}^{\,0}\right) = -D_{AB}\frac{dC_A}{dx}$$

$\frac{C_{A1}}{L}$

$$\frac{C_B}{C} N_A = -D_{AB} \frac{dC_A}{dx}$$

$$\frac{C - C_A}{C} N_A = -D_{AB} \frac{dC_A}{dx}$$

$$\int_{C_{A1}}^{C_{A2}} \frac{dC_A}{C - C_A} = - \int_0^L \frac{N_A}{D_{AB} C} dx$$

$$-\ln\left(\frac{C - C_{A2}}{C - C_{A1}}\right) = -\frac{N_A}{D_{AB} C} L$$

$$N_A = \frac{D_{AB} C}{L} \ln\left(\frac{C - C_{A2}}{C - C_{A1}}\right)$$

$$= \frac{D_{AB} C}{L} \frac{C_{A1} - C_{A2}}{\dfrac{C_{A1} - C_{A2}}{\ln\left(\dfrac{C - C_{A2}}{C - C_{A1}}\right)}}$$

$$= \frac{D_{AB} C}{L} \frac{C_{A1} - C_{A2}}{\dfrac{C_{B2} - C_{B1}}{\ln\left(\dfrac{C_{B2}}{C_{B1}}\right)}}$$

$$\downarrow$$

$$C_{Blm}$$

$$N_A = \frac{D_{AB} C}{L} \frac{C_{A1} - C_{A2}}{C_{Blm}}$$

Gas phase

$$C = \frac{P}{RT}, \quad C_A = \frac{P_A}{RT}$$

$$y_A = \frac{C_A}{C} = \frac{P_A}{P}$$

Liquid phase $\quad x_A = \frac{C_A}{C}$

$$\frac{dN_A}{dx} = 0 \Rightarrow N_A \neq f(x)$$

$$N_A = -\frac{D_{AB}C}{C - C_A}\frac{dC_A}{dx}$$

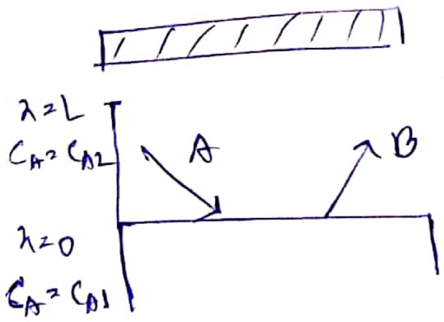
$$N_A \int_0^x dx = -D_{AB}C \int_{C_{A1}}^{C_A} \frac{dC_A}{C - C_A}$$

$$N_A x = D_{AB}C \ln\left(\frac{C - C_A}{C - C_{A1}}\right)$$

$$\therefore \frac{\cancel{D_{AB}C}}{L} \ln\left(\frac{C - C_{A2}}{C - C_{A1}}\right) x = \cancel{D_{AB}C} \ln\left(\frac{C - C_A}{C - C_{A1}}\right)$$

$$\frac{C - C_A}{C - C_{A1}} = \left(\frac{C - C_{A2}}{C - C_{A1}}\right)^{x/L}$$

$$\text{Depletion} = \frac{\text{Mass}}{N_A A}$$



$A\uparrow \; -B\uparrow$

equimolar $N_A = -N_B$

Non " $N_A = -nN_B$

$$N_A - \frac{C_A}{C}(N_A + N_B) = -D_{AB}\frac{dC_A}{dx}$$

equimolar : $N_A = -N_B$ $\quad N_A + N_B = 0$

$$N_A = -D_{AB}\frac{dC_A}{dx} \; , \quad (\text{no convective flux})$$

$$N_A = -\frac{D_{AB}}{L}(C_{A2} - C_{A1}) = \frac{D_{AB}}{L}(C_{A1} - C_{A2})$$

Fick's 2nd Law $\quad \frac{d^2 C_A}{dx^2} = 0$

$$C_A = Ax + B$$

$x = 0, \; C_A = C_{A1}$ $\qquad C_{A1} = B$

$x = L \quad C_A = C_{A2}$ $\qquad C_{A2} = AL + B$ $\qquad \therefore A = \frac{C_{A2} - C_{A1}}{L}$

Scanned by CamScanner

$$C_A = (C_{A2} - C_{A1})\frac{x}{L} + C_{A1}$$

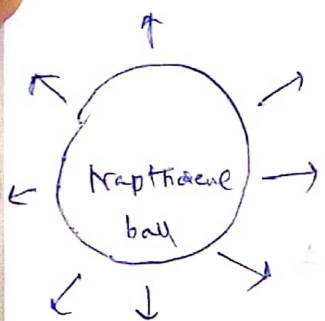
01.08.2019

$$\frac{C_A - C_{A1}}{C_{A2} - C_{A1}} = \frac{x}{L}$$

Variable Geometry of System

→ A ↑ B ≠ $N_A = ?$ $C_A = ?$

→ A ↑ B ↓ $N_A = ?$ $C_A = ?$



A ↑ B ≠

$$\frac{d}{dx}(N_A A) = 0$$

$$\frac{d}{dr}(N_A 4\pi r^2) = 0$$

$$N_A 4\pi r^2 = \text{Const} = W \quad (\neq f(r))$$

$$N_A - \frac{C_A}{C}(N_A + \cancel{N_B})^{0} = -D_{AB}\frac{dC_A}{dx}$$

$$\frac{C - C_A}{C} N_A = -D_{AB}\frac{dC_A}{dr}$$

$$\frac{C - C_A}{C}\cdot\frac{W}{4\pi r^2} = -D_{AB}\frac{dC_A}{dr}$$

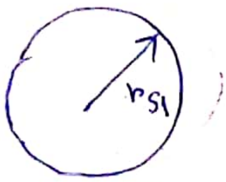
$$-\frac{W}{D_{AB}C}\int_{r_s}^{\infty}\frac{dr}{4\pi r^2} = \int_{C_{As}}^{C_{A\infty}}\frac{dC_A}{C - C_A}$$

$$\frac{W}{D_{AB}C4\pi}\left(\cancel{\ } - \frac{1}{r_s}\right) = -\ln\left(\frac{C - C_{A\infty}}{C - C_{As}}\right)$$

$$\frac{C - C_{A\infty}}{C - A_s} = \exp\left(\frac{W}{D_{AB}C4\pi r_s}\right)$$

$$W = D_{AB}\, C\, 4\pi r_s \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right)$$

$r_s : r_{s1} \longrightarrow r_{s0}$



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

$$= - D_{AB}\, C\, 4\pi r_s \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right)$$

$$- 4\cancel{\pi} r_s^2 \frac{dr_s}{dt} \frac{\rho_A}{M_A} = D_{AB}\, C \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right) 4\cancel{\pi} r_s$$

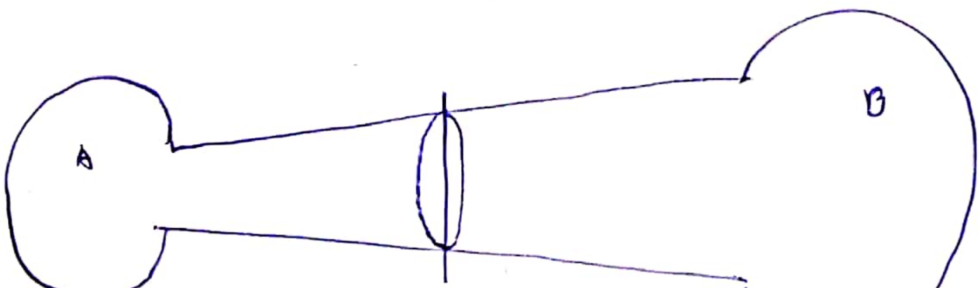
$$- \int_{r_{s1}}^{r_{s0}} r_s \, dr_s = \frac{D_{AB} C M_A}{\rho_A} \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right) \int_0^t dt$$

$$\cancel{\ln\left(\frac{r_{s0}}{r_{s1}}\right)} = - \frac{D_{AB} C M_A t}{\rho_A} \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right)$$

$$\frac{1}{2}\left(r_{s0}^2 - r_{s1}^2\right)$$

For Complete Sublimation

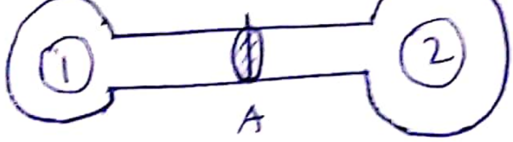
$$\frac{1}{2} r_{s1}^2 = \frac{D_{AB} C M_A}{\rho_A} T \ln\left(\frac{C - C_{A\infty}}{C - C_{AS}}\right)$$



$N_A = f(z)$

Diffusivity Measurement

- Gas
  - Stefan tube
  - Twin bulb
- Diphragm Cells



$$-\frac{d}{dt}(V_1 C_{A1}) = N_A a = \frac{D_{AB}\, a}{l}(C_{A1} - C_{A2})$$

$$\frac{d}{dt}(V_2 C_{A2}) = \frac{D_{AB}\, a}{l}(C_{A1} - C_{A2})$$

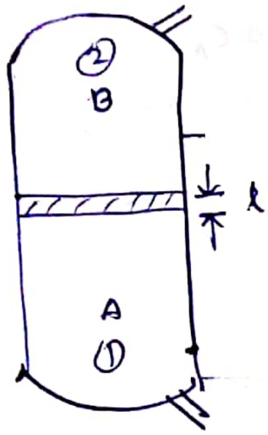
$$-\frac{d}{dt} C_{A1} = \frac{D_{AB}\, a}{l V_1}(C_{A1} - C_{A2})$$

$$\frac{d}{dt} C_{A2} = \frac{D_{AB}\, a}{l V_2}(C_{A1} - C_{A2})$$

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

$$-\ln\left(\frac{C_{A1f} - C_{A2f}}{C_{A10} - C_{A20}}\right) = \frac{D_{AB}\, a}{l}\left(\frac{1}{V_1} - \frac{1}{V_2}\right)t$$

Diaphragm Cell :



$t = 0, \quad C_{A1} = C_{A10}$

$C_{B1} = C_{B10} = 0$

$C_{A2} = C_{A20} = 0$

$C_{B2} = C_{B20}$

$t = t_f, \quad C_{A1} = C_{A1f}$

$C_{B1} = C_{B1f}$

$$N_A a = \frac{1}{V_1} \frac{D_{AB}\, a\, \epsilon}{l\, \tau} (C_{A1} - C_{A2})$$

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

$$\text{Cell Const} = \frac{a}{l} \frac{\epsilon}{\tau} \left(\frac{1}{V_1} - \frac{1}{V_2}\right) \qquad = D_{AB} K_{cell} (C_{A1} - C_{A2})$$

$W \propto \Delta$ Driving force (Δ D.F)

$W \propto a$

$W \propto a\, \Delta DF \qquad N_A \propto \Delta DF$

$N_A = (MTC)\, \Delta DF$

MTC $\rightarrow$ Mass Transfer Co-efficient

$N_A = K_c (\Delta C_A)$ — Gas phase

$= K_L (\Delta C_A)$ (liq phase)

$N_A = K_y (\Delta y_A)$ (Gas phase)

$= K_x (\Delta x_A)$

$N_A = K_p\, \Delta P_A$

$= K_G\, \Delta P_A$

$$N_A = K_c \Delta C_A$$
$$= K_y \Delta y_A$$
$$= K_G \Delta P_A$$

Gas

$$N_A = K_L \Delta C_A$$
$$= K_x \Delta C_A$$

Liq

$$c K_c = K_y$$
$$K_G RT = K_c$$

① A ↑ B ≠ $\quad K_c \quad K_y \quad K_G \quad K_L \quad K_x$

② A ↑ , B ↓ - - - - - - -

① A ↑ B ≠

$$N_A = \left[\frac{D_{AB}\, C}{l\, C_{Blm}}\right] \underbrace{(C_{A1} - C_{A2})}_{\Delta C_A}$$

$$K_c = \frac{D_{AB}\, C}{l\, C_{Blm}} \qquad K_L = \frac{D_{AB}\, C}{l\, C_{Blm}}$$

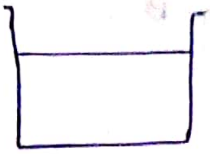
$$N_A = \frac{D_{AB}\, C}{l\, C_{Blm}}\, C\left(y_{A1} - y_{A2}\right)$$

$$K_y = \frac{D_{AB}\, C^2}{l\, C_{Blm}} \qquad K_x = \frac{D_{AB}\, C^2}{l\, C_{Blm}}$$

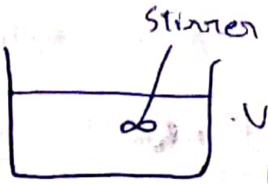
$$N_A = \frac{D_{AB}\, P}{l\, P_{Blm}} \left(P_{A1} - P_{A2}\right) \frac{1}{RT}$$

$$K_G = \frac{D_{AB}\, P}{l\, P_{Blm}\, RT}$$

fashionable Product → 2-6 month



Molecular Diffusion



Velocity Field → Turbulence → more mixing

Eddy Diffusion

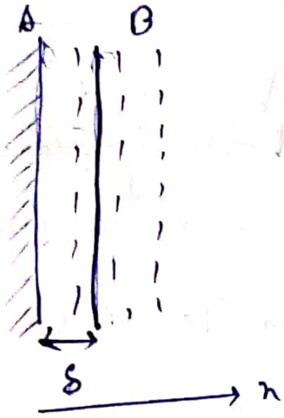
Convective Mass Transfer

$$N_A = (MTC)(\Delta D.F.)$$

$$N_A = K_C(\Delta C_A) = K_L(\Delta C_A)$$
$$= K_y(\Delta y_A) = K_x(\Delta x_A)$$
$$= K_p(\Delta P_A)$$

MTC
- Analytical
  - Mol. Diff
  - Convective MT. Theories
    - Film Theory
    - Penetration "
    - Surface Renewal "
    - Boundary Layer Theory
- Correlation
  - Experimental (Derived from Experimental Data)
  - Analogous

1\.



A is soluble in B.

Film Theory

1. Applicable to liquid past solid
2. Steady state
3. Convective Flux = 0

$\Rightarrow (N_A + N_B)\frac{C_A}{C} = 0$

$x = \delta,\ C_A = C_{AB}$
$x = 0,\ C_A = C_{AS}$

4. Stagnant film → Mass Transfer ~~coeff~~ Resistance $\left(\frac{1}{K_c}\right)$ will lie in the film

5. within film $(x = \delta)$, Mol. Diff. occurs ∴ Fick's Law applicable

$$\frac{dN_A}{dx} = 0 \qquad N_A - J_A = \text{convective Flux} = 0$$

$$\therefore \frac{dJ_A}{dx} = 0 \qquad \frac{dN_A}{dx} = -\frac{dJ_A}{dx}$$

$$\frac{C_A - C_{Ai}}{C_{Al} - C_{Ai}} = \frac{x}{\delta} \qquad x = 0,\ C_A = C_{Ai} \quad x = \delta,\ C_A = C_{Al}$$

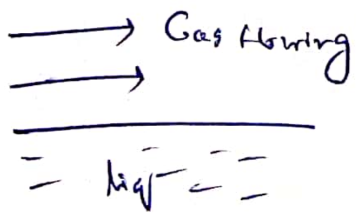
$$N_A = \frac{D_{AB}}{\delta}(C_{Ai} - C_{Al})$$

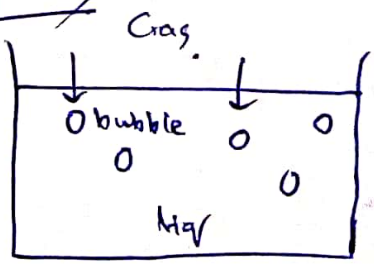
$$\therefore K_L = \frac{D_{AB}}{\delta}$$

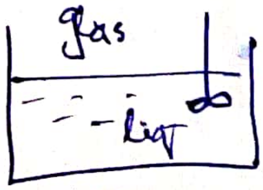
Experimentally $K_L \propto D_{AB}^{n}\ (n<1)$

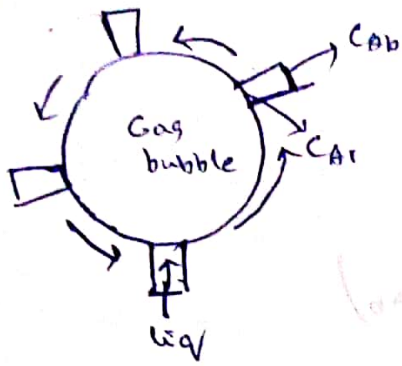
Velocity ↑ δ ↓ N_A ↑

Penetration Theory (Highbie)









① Applicable to Gas–liq system

② Un Steady State

③ MT occurs during Contact Time.

④ Contact Time is so low that that liq element behave as infinity slab

T_c is NOT Varying (constant)

$$N_A = K_L \Delta C_A = K_L \Delta C_A$$
$$= K_y \Delta y_A = K_x = \Delta x_A$$
$$= K_p \Delta P_A$$

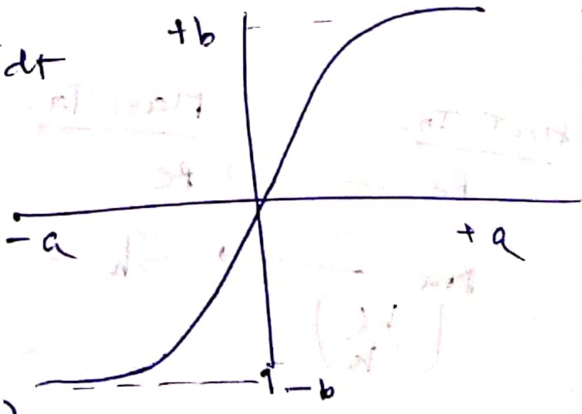
$$\frac{\partial^2 C_A}{\partial x^2} = \frac{\partial C_A}{\partial t}$$

$$C_A(0, x) = C_{Ab}$$
$$C_A(t, 0) = C_{Ai}$$
$$C_A(t, \infty) = C_{Ab}$$

$$\frac{C - C_{Ab}}{C_{Ai} - C_{Ab}} = 1 - \text{erf}\ \eta$$

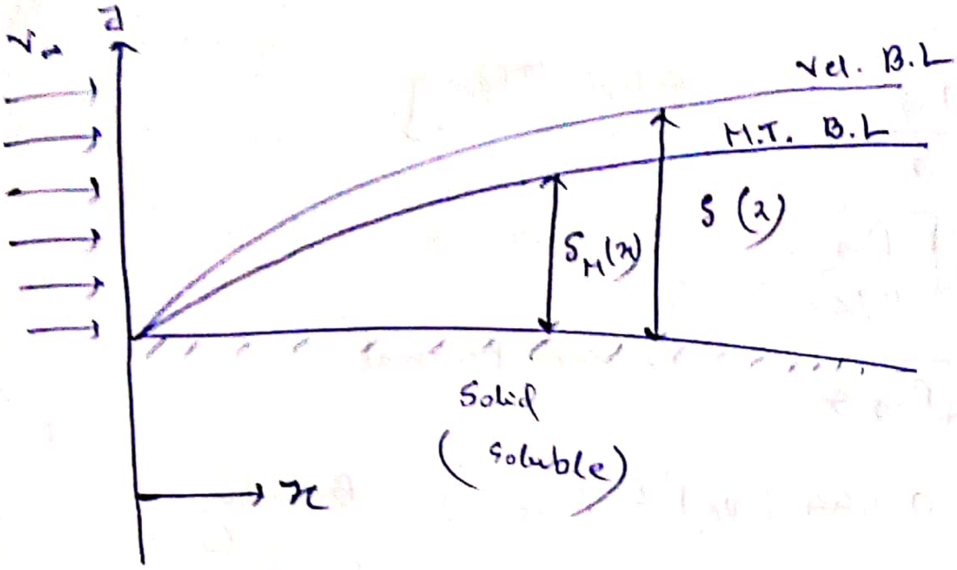
$$\eta = \frac{l}{2\sqrt{D_{AB}\, t}}$$

$$\text{erf} = \frac{1}{\sqrt{\pi}} \int_{+x}^{-x} e^{-t^2}\, dt$$



$$N_A(t) = -D_{AB} \frac{dC_A}{dx}$$
$$= \sqrt{\frac{D_{AB}}{\pi t}} \left(C_{Ai} - C_{Ab} \right)$$

months



$0 < y < \delta(x)$

$V = V(x, y)$

$y = \delta(x)$

$V = 0.99 V_\infty$

$y > \delta(x)$

$V = V_\infty$

$y = 0, \quad C_A = C_{Ai}$

$y = \delta_M(x) \quad C_A = C_{Ai} - (C_{Ai} - C_{Ab})\, 0.99$

$y > \delta_M(x) \quad C_A = C_{Ab}$

$$\frac{K_{cx}\, x}{D_{AB}} = 0.322 \left(\frac{x V_\infty \rho}{\mu}\right)^{1/2} \left(\frac{\nu}{D_{AB}}\right)^{1/3}$$

$$Sh|_x = 0.322 (Re_x)^{1/2} Sc^{1/3}$$

$$Sh|_{av} = 0.644\, Re^{1/2}\, Sc^{1/3}$$

$$Sh = f(Re, Sc)$$

Film, Penetration, S.R $\longrightarrow$ Implicit

B.L $\longrightarrow$ explicit

$\longrightarrow$ $Sh = f(Re, Sc)$

19.08.2019

$N_A = K_c \Delta C_A = K_L \Delta C_A$

$= K_y \Delta y_A = K_x \Delta x_A$

$= K_p \Delta P_A$

$$K_c = \frac{D_{AB}}{\delta}$$ Film Theory

$$= 2\sqrt{\frac{D_{AB}}{\pi t_c}}$$ Penetration "

$$= \sqrt{D_{AB}\, S}$$ Surface Renewal "

$$Sh = 0.644\,(Re)^{1/2}\,(Sc)^{1/3}$$ Boundary Layer "

$$Sh = f(Re, Sc)$$

$$Sh = \frac{\text{Conv. MT}}{\text{mol Diff MT}}$$

$$= \frac{K_c\, l}{D_{AB}} \approx Nu$$

$$Re = \frac{L V_\infty \rho}{\mu}$$

$$Sc = \frac{\nu}{D_{AB}} \approx Pr$$

$$Pe_{HT} = Re\, Pr$$

$$Pe_{MT} = Re\, Sc$$

$$St_{HT} = \frac{Nu}{Re\, Pr} = \frac{Nu}{Pe}$$

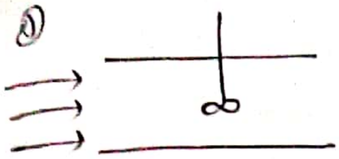
$$St_{M-T} = \frac{Sh}{Re\, Sc}$$

MTC — Correlations

① Experimental Data & Dimensional Analysis

② Analogous H.T. Correlation

①



Nature of A and B
Velocity
Matterial Properties (ρ...)
Transport Properties (α, D_{AB}, ν)
Dimeter of Pipe

Parameter	W_A	N_A	K_c

$Sh = f(Re, Sc)$
Find f (function)

②

$$Nu = f(Re, Pr)$$
$$Sh = f(Re, Sc)$$

Reynold's Analogy :

$$St_H = St_M = \frac{f}{2} \qquad f = \text{friction factor}$$

valid when $Sc, Pr \approx 1$

$$St_H Pr^{2/3} = St_M Sc^{2/3} = \frac{f}{2}$$

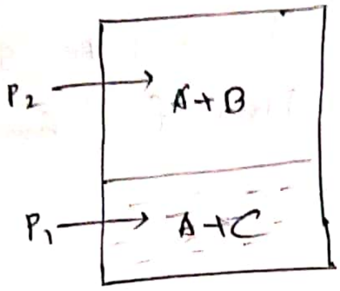
$$J_H = J_M = \frac{f}{2}$$

Coubwrn factor (Coulburn-Chilton Analogy)

$Sh = 2$ when air is Stagnant, Naphthalene is sublimed.

$$Sh = \frac{K_c \Delta C_A}{\frac{D_{AB}}{S} \Delta C_A} =$$

MT
- Binary System
- Steady State
- No Reaction
- homogenous / Single Phase

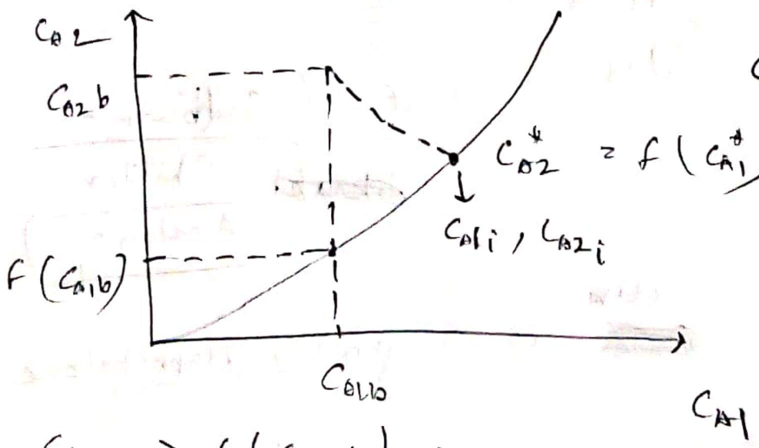


Gas – Liq
Liq – Gas
Liq – Liq

① $C_{A2b} = f(C_{A1b})$ → Equilibrium
No MT

$C_{A2b} \neq f(C_{A1b})$ → No Equilibrium
MT

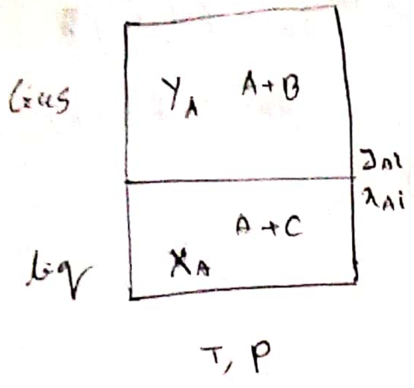
② $C_{A2b} > f(C_{A1b})$
MT: Phase 2 > Phase 1



$C_{A2} = f(C_{A1})$

$C^*_{A2} = f(C^*_{A1})$

$C_{A2b} > f(C_{A1}, b)$: MT: Phase 2 → Phase 1

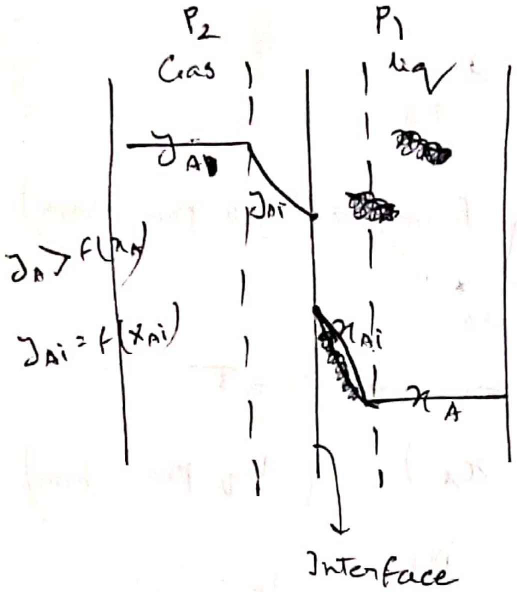


$y_A = f(x_A)$ ... At Equilibrium

Whitman: (Hypothesis)

Two Field Theory /

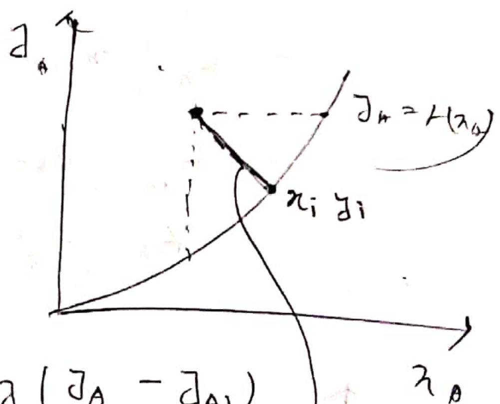
Two Resistance Theory



① A is moving from bulk phase to interface
→ film on both side produces all the resistance to the MT.

② Establishing equilibrium at interface
→ No. Resistence

liq → gas : leaching
gas → liq : Adsorption



Gas $\quad N_A = k_y \Delta y_A = k_y(y_A - y_{Ai})$

Liquid: $\quad N_A = k_x \Delta x_A = k_x(x_{Ai} - x_A)$

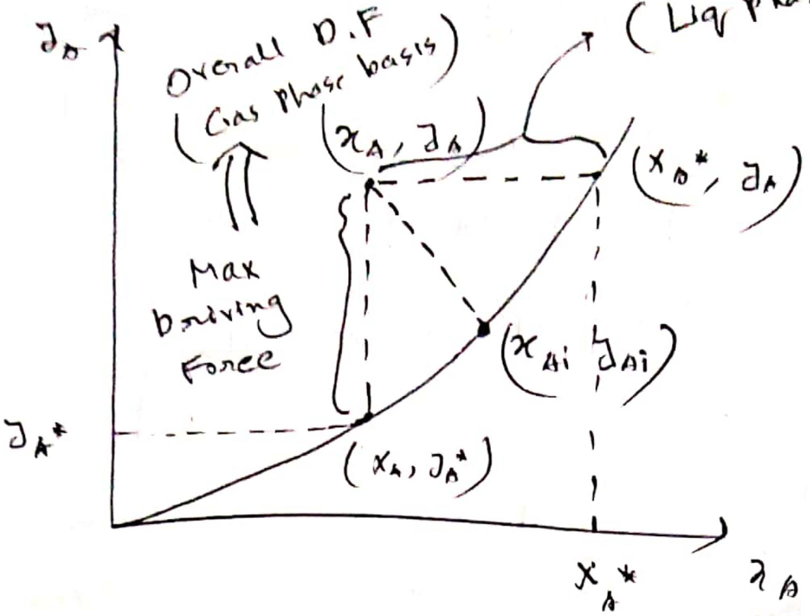
slope of the line

$$\frac{y_A - y_{Ai}}{x_A - x_{Ai}} = -\frac{k_x}{k_y}$$

Overall D.F (Liq phase Basis)

$y_A = f(x_A^*)$

$y_A^* = f(x_A)$



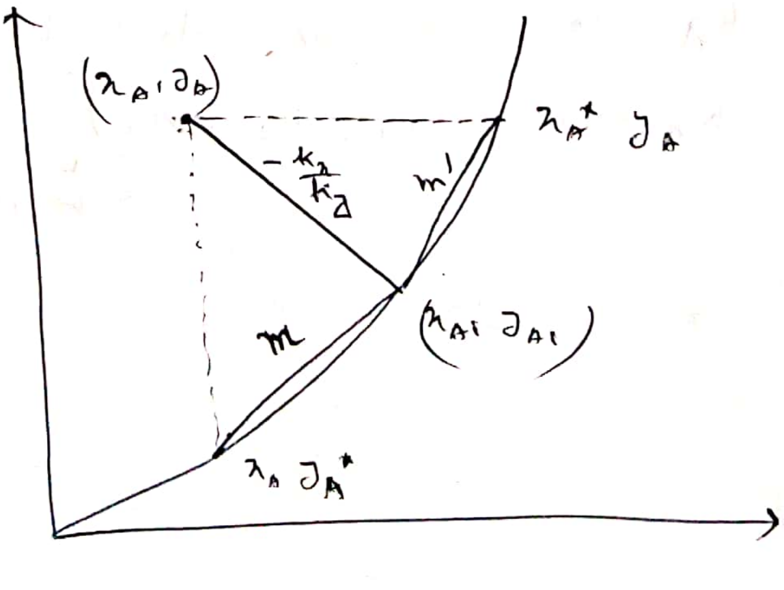
$N_A \propto$ (Overall Driving force) $\rightarrow$ (gas phase basis)

$N_A = K_y (y_A - y_A^*)$

$K_y \equiv$ Overall Mass Transfer Co-efficient

$N_A = K_x (x_A^* - x_A)$ (Liq phase basis)

$$
\begin{aligned}
N_A &= k_y (y_A - y_{Ai}) & \frac{N_A}{k_y} &= y_A - y_{Ai} \\
&= k_x (x_{Ai} - x_A) & \frac{N_A}{k_x} &= x_{Ai} - x_A \\
&= K_y (y_A - y_A^*) & \frac{N_A}{K_y} &= y_A - y_A^* \\
&= K_x (x_A^* - x_A) & \frac{N_A}{K_x} &= x_A^* - x_A
\end{aligned}
$$



$$\frac{N_A}{k_y} = y_A - y_{Ai} + y_{Ai} - y_A^*$$

$$= \frac{N_A}{k_y} + \frac{y_{Ai} - y_A^*}{x_{Ai} - x_A^*}\left(x_{Ai} - x_A\right)$$

$$= \frac{N_A}{k_y} + m\frac{N_A}{k_x}$$

$$\therefore \quad \frac{1}{K_y} = \frac{1}{k_y} + \frac{1}{k_x} m$$

M.T Resistence by gas phase to overall MT resistence

M.T Resistence by liq phase to overall M.T. Resistence

Overall Mass Transfer Resistence (gas phase basis)

$$\frac{N_A}{K_x} = x_A^* - x_{Ai} + x_{Ai} - x_A$$

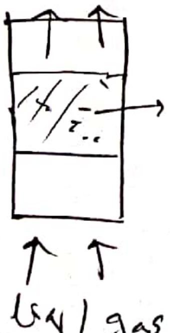
$$= \left(\frac{x_A^* - x_{Ai}}{y_A - y_{Ai}}\right)\left(y_A - y_{Ai}\right) + \frac{N_A}{k_x}$$

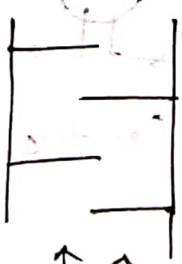
$$= \frac{1}{m'}\left(\frac{N_A}{k_y}\right) + \frac{N_A}{k_x}$$

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

M.T. Equipements:

- Continuous
  - Co-current
  - Counter Current
- Stagewise





$N_A \Rightarrow$ local MTC $\Rightarrow$ Interfacial Conc.

Overall MTC $\Rightarrow$ Two basis → Gas phase
→ Liq phase

Gas phase basis K_y, K_G, K_c
Liq " " K_x, K_L

N_A = Overall MTC × Deviation from Equillibrium

Overall MT R/. = Liq phase Resistance
+ Gas phase Resistance

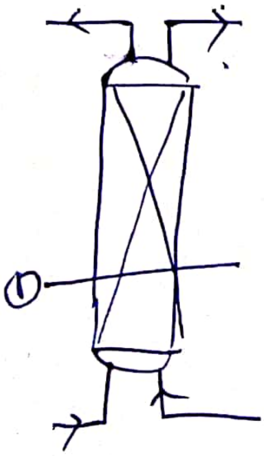
$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{m}{k_x}$$

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

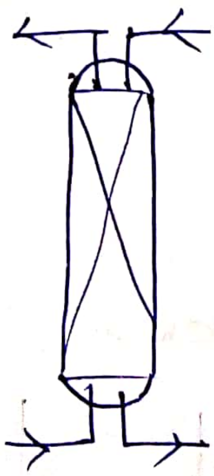
MT Equipment:

Continuous Operation

Stage wise Operation

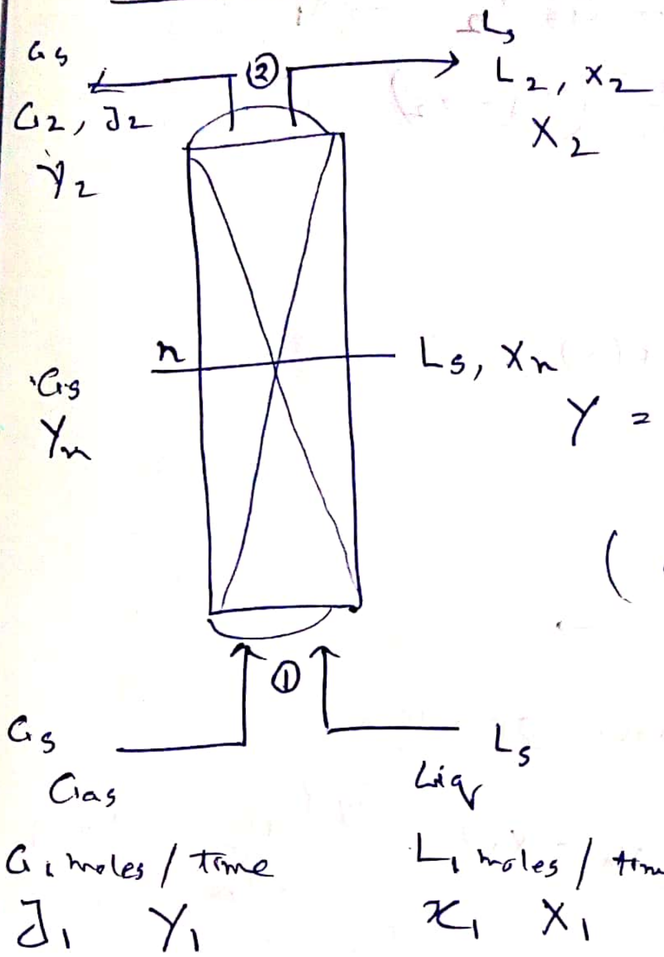


Co-current



Counter current

Co-Current Continuous Operation



G_s = All the moles Except solute which is being transfered

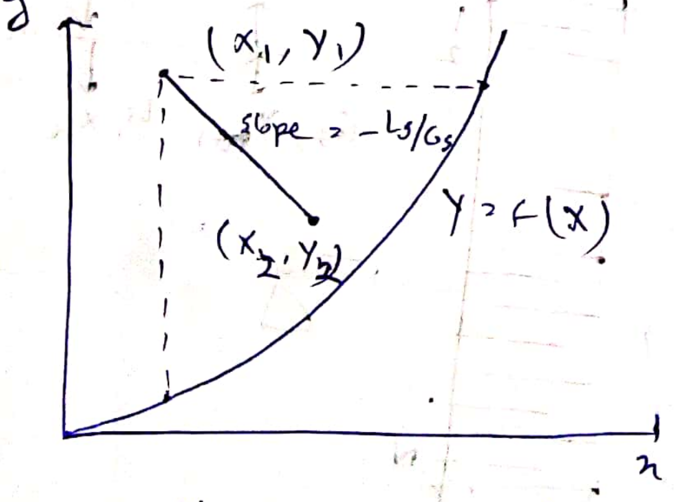
$G_s = G(1-y)$

$Y = \dfrac{\text{Mole fraction of A}}{\text{Mole fraction of B}}$ (in a Binary Mixture)

$Y = \dfrac{y}{1-y}$

$$G_sY_1 + L_sX_1 - G_sY_n - L_sX_n = 0$$

$$Y_1 - Y_n = -\frac{L_s}{G_s}(X_1 - X_n)$$ operating Line Equation



$y = f(x)$

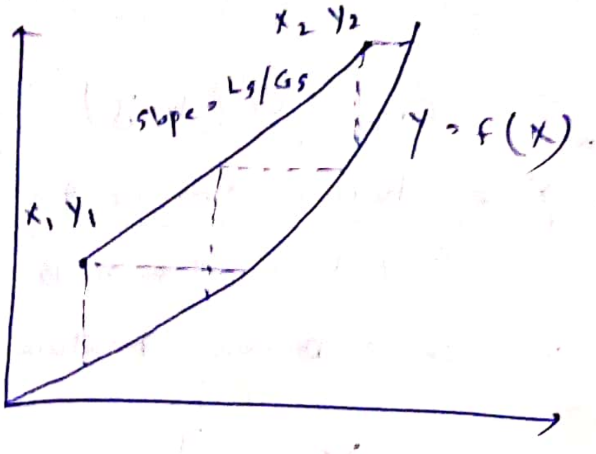
$\Rightarrow Y = f(X)$

$$Y_1 - Y_2 = -\frac{L_s}{G}(X_1 - X_2)$$

For Counter Current

$$G_s Y_1 + L_s X_2 - G_s Y_2 - L_s X_1 = 0$$

$$Y_1 - Y_2 = \frac{L_s}{G_s}(X_1 - X_2)$$



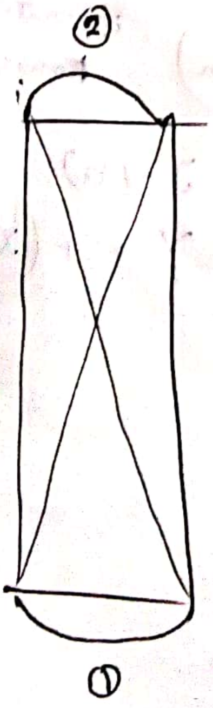
Co-Current Continuous Operation

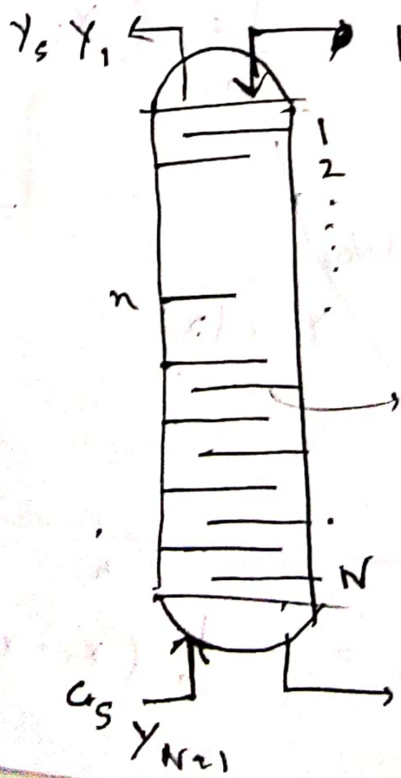
$$Y_n - Y_1 = -\frac{L_s}{G_s}(X_n - X_1)$$

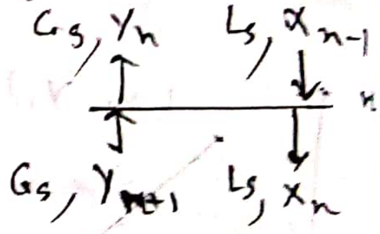
$$G_s Y_{n+1} + L_s X_{n-1}$$
$$= G_s Y_n + L_s X_n$$
$$Y_{n+1} - Y_n = \frac{G_s}{L_s}(X_{n-1}$$

Countercurrent

$$Y_n - Y_1 = \frac{L_s}{G_s}(X_n - X_1)$$



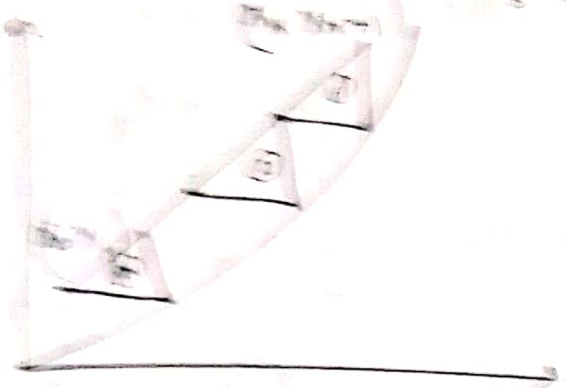




$$G_s Y_{n+1} + L_s X_0 = G_s Y_1 + L_s X_n$$

$$Y_{n+1} - Y_1 = \frac{L_s}{G_s}(X_n - X_0)$$

$$(Y_{n+1} - Y_1) = \frac{L_s}{G_s}(X_n - X_0)$$



Analytical soln is possible if Eq'n of equilibrium is linear.

$Y = \alpha X$

$P \rightarrow 14.5, 14.6$

$$Y_{n+1} - Y_1 = \frac{L_s}{G_s}\left(\frac{Y_n}{\alpha} - X_0\right)$$

$$= \frac{L_s}{G_s \alpha} Y_n - \frac{L_s}{G_s} X_0 = \bar{A} Y_n - \frac{L_s}{G_s} X_0$$

$\bar{A}$

$$= \bar{A} Y_n - \bar{A}\alpha X_0$$

$$Y_{n+1} - \bar{A} Y_n - Y_1 = -\bar{A}\alpha X_0 \qquad = Y_1 - \bar{A}\alpha X_0$$

at $n = 0$, $\quad Y_n = Y_{n+1}$

" $n = 1$, $\quad Y_n = Y_1$

$$Y_{n+1} = \left(\frac{\alpha X_0 - Y_1}{1 - \bar{A}}\right) \bar{A}^{N+1}$$

$$B_{N+1} = \frac{Y_1 - \bar{A}\alpha X_0}{1 - \bar{A}}$$

$$N = \frac{\log\left(\left(\frac{Y_{N+1} - \alpha X_0}{Y_1 - \alpha X_0}\right)\left(1 - \bar{A}\right) + \frac{1}{\bar{A}}\right)}{\log \bar{A}}$$

Kremser eq'n

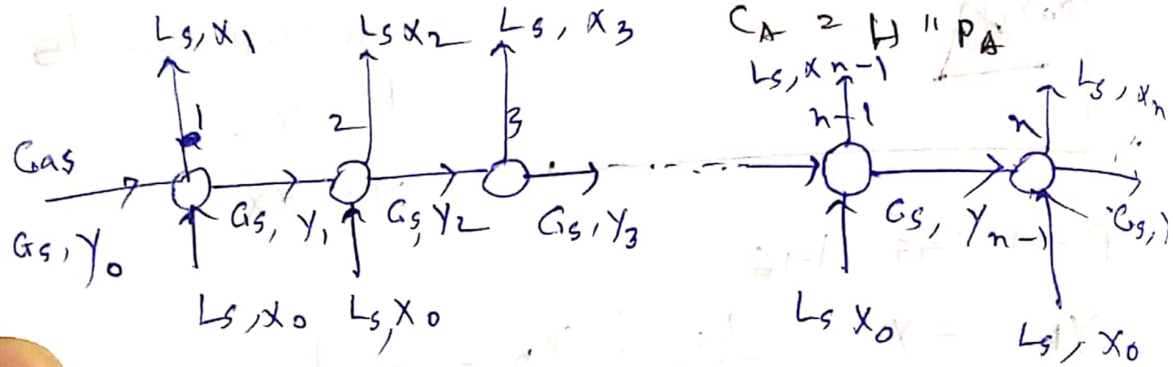
$$N = \frac{\log\left[\left(\frac{x_0 - Y_{N+1}/\alpha}{x_0 - Y_{N+1}/\alpha}\right)\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right]}{\log \frac{1}{A}}$$

Raoult's Law, Henry's law

$$y_A = m x_A$$

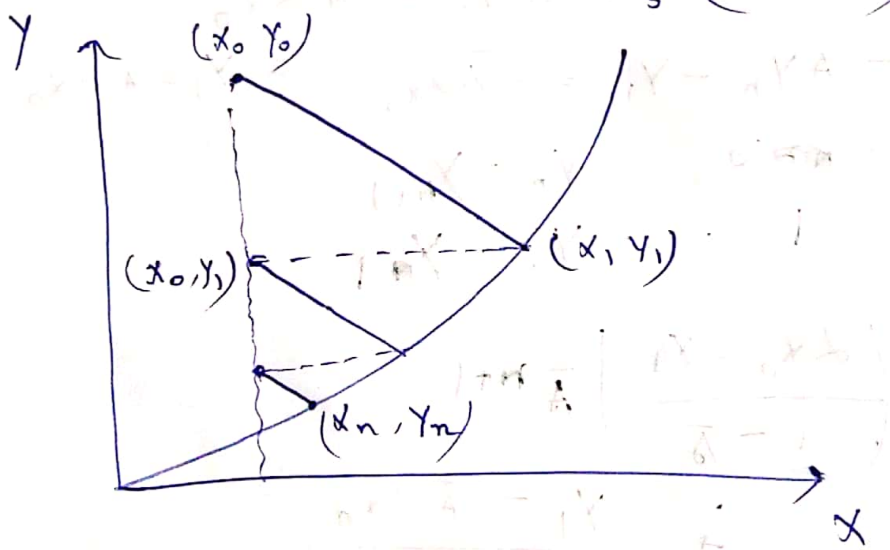
$$p_A = H x_A$$
$$= H' C_A$$

$$C_A = H'' p_A$$



$$G_s Y_{n-1} + L_s X_0 = G_s Y_n + L_s X_n$$

$$Y_n = Y_{n-1} - \frac{L_s}{G_s}(X_n - X_0)$$



1. Crystallization :

Separation of solute from solution to ~~liquid~~ solid phase.

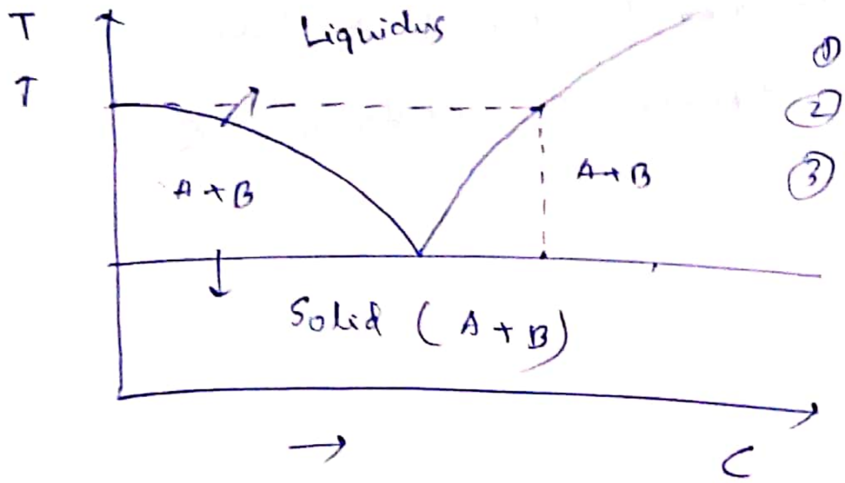
Solution : Supersaturated $C > C^*$ → Neucleation

↓

Growth of Crystals → CSD (Pat) Crystal size Distribution

$A \to A$
$c(1-s) \quad cs$
$K = \frac{cs}{c(1-s)}$

Degree of SuperSaturation $S = \frac{C - C^*}{C}$



1. Cooling
2. Evaporation
3. Altering Equi. Curve

Neucleating Agent

Neucleation → homogenous, heterogeneous

L = size

Neucleation Rate, $B_0 = \lim_{L \to 0} \frac{d}{dt}\left(N(L)/V\right)$

$= \frac{d}{dt}\left(N(0)/V\right)$

$B_0 = K_r, M_T S^n$

found by Experiments

Order of Crystallisation

$n = (0, 5)$

$n = 2$ (mostly)

L : $A = \phi_a L^2$

Characteristic Length $V = \phi_a L^3$

Rate of Growth $\frac{dL}{dt} = G$

$$\underbrace{G = K_2 s^m \qquad B_0 = K_1 M_T s^n}_{\text{Competing Process}}$$

McCabe ΔL law $G \neq f(L)$

Growth Rate does'nt Depend on size

Final size depends on Residence Time