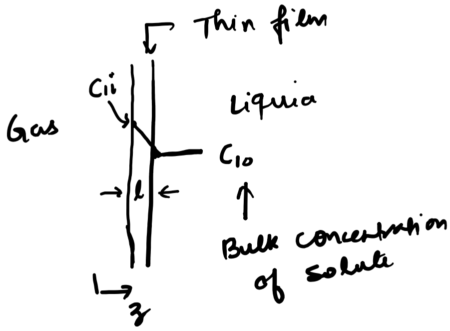
Theories of Mass Transfer

Fluid - fluid : Distillation, liquid - liquid extraction

Fluid - solid : Adsorption

Theories of mass transfer relate the mass transfer coefficient with molecular diffusivity & fluid flow (velocity)

1) The film theory : We will consider dilute solutions.



C_{1i} = Concentration of solute in liquid phase at the gas-liquid interface

C_{10} : Bulk conc. of solute in liquid

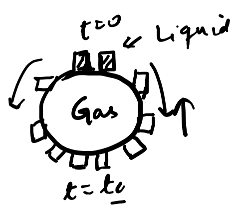
At steady state : $N_1 = K(C_{1i} - C_{10}) = -D_{AB}\dfrac{dC}{dz}$

$$\Rightarrow K(C_{1i} - C_{10}) = D_{AB}\left(\frac{C_{1i} - C_{10}}{l}\right)$$

$$\Rightarrow \boxed{K = \frac{D_{AB}}{l}}$$

- Effect of fluid velocity is taken into account by 'l', the film thickness.
    - velocity is large, 'l' is small & vice-versa
- In practice, the film thickness 'l' cannot be obtained easily & therefore the theory is not practically useful

2) Penetration theory : Mass transfer taking place between gas & liquid



Assumptions :

(i) The mass transfer is "unsteady" as t_c is small

(ii) Equilibrium exist at the gas-liquid interface

(iii) t_c is same for all bubbles

$$\frac{\partial C_A}{\partial t} = D_{AB} \frac{\partial^2 C_A}{\partial z^2}$$

Initial conditions:

$t=0, \quad z \geq 0, \quad C_A = C_{Ab}$ ← Bulk conc in liquid

Boundary conditions

$t>0, \quad z=0, \quad C_A = C_{Ai}$ ← Equilibrium conc. at gas - liquid interface.

$t>0, \quad z \to \infty, \quad C_A = C_{Ab}$

$$\frac{C_A - C_{Ab}}{C_{Ai} - C_{Ab}} = 1 - erf(\eta); \quad \eta = \frac{z}{2\sqrt{D_{AB} t}}$$

$$N_A(t) = -D_{AB} \left.\frac{dC_A}{dz}\right|_{z=0}$$

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

$$\text{Average flux} = N_{A,av} = \frac{1}{t_c} \int_0^{t_c} N_A(t)\, dt = 2\sqrt{\frac{D_{AB}}{\pi t_c}} (C_{Ai} - C_{Ab})$$

$$\text{Instaneous mass transfer coefficient, } k_L = \sqrt{\frac{D_{AB}}{\pi t}}$$

$$\text{Average mass transfer coefficient, } k_{L,av} = 2\sqrt{\frac{D_{AB}}{\pi t_c}}$$

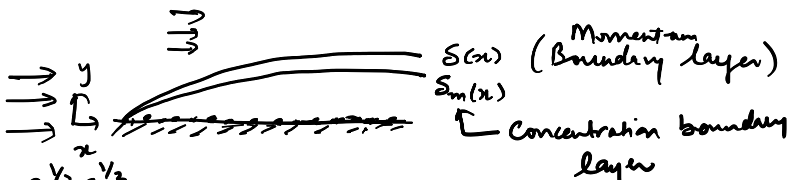
3) <u>Surface Renewal Theory</u>: t_c is not uniform for all bubbles but has a distribution.

$$k_L = \sqrt{D_{AB}\, s} \quad ; \quad s = \text{Surface renewal rate}$$

If the turbulence increases, then s is large & thus k_L is large.

4) <u>The boundary layer theory</u>:

According to this theory:



$$Sh_{,x} = \frac{k_{L,x}\, x}{D_{AB}} = 0.332\, Re_x^{1/2} Sc^{1/3}$$

$$Sh_{,av} = \frac{k_{L,av}\, l}{D_{AB}} = 0.664\, Re_l^{1/2} Sc^{1/3}$$

l: Length of the plate

$$Re_{,x} = \frac{\rho V_\infty x}{\mu}$$

$$Sc = \frac{\mu/\rho}{D_{AB}} \quad ; \quad \frac{\delta}{\delta_m} = Sc^{1/3}$$