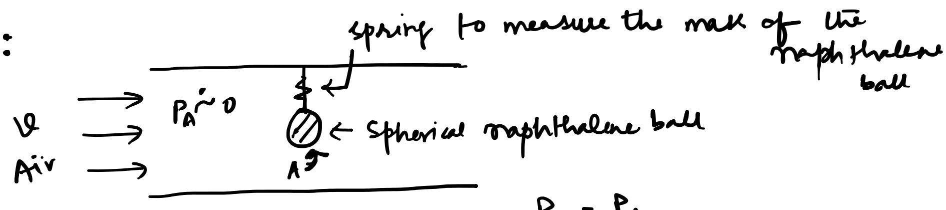
Mass Transfer Coefficient : Empirical Correlations

Empirical Correlations :



$P_A = P_{As}$

Parameters :

(i) Air velocity
(ii) Diameter of the naphthalene ball
(iii) Temperature
(iv) Use another gas (N_2, CO_2, etc) instead of Air

Initially: $t = 0$ $\quad m_b = m_0$

$t = t_1 : m_b = m_1 \Rightarrow$ Change in mass, $\Delta m = (m_0 - m_1)$

$\Delta t = (t_1 - 0)$

flux $= N = \left[\dfrac{\Delta m}{M_w \, \Delta t \; 4\pi r^2}\right]$

$$N_A = k(\text{driving force}) = k_G(\Delta P) = k_G(P_{As} - 0)$$

$$\Rightarrow k_G = \frac{\Delta m}{M_w \Delta t \,(4\pi r^2)\, P_{As}}$$

$$k_G = f(v, \rho, d, \text{etc})$$

Dimensionless Numbers :

(i) Reynolds number

(ii) Sherwood number : $Sh = \dfrac{\text{convective mass (or molar) flux}}{\text{mass (or molar) flux for molecular diffusion through a stagnant medium of thickness } l \text{ under the driving force } \Delta P_A}$

Similar to Nu in heat transfer

Ex : Diffusion of A in non diffusing B :

Convective flux $= K_G \Delta P_A$

Molecular diffusive flux $= \dfrac{D_{AB} P}{R T l \, P_{Bm}} \Delta P_A$

$$Sh = \frac{K_G \Delta P_A}{\frac{D_{AB} P}{RT l P_{Bm}} \Delta P_A} = \frac{\frac{K_G P_{Bm} RT l}{D_{AB} P}}{}$$

(iii) Schmidt number (Sc):

$$Sc = \frac{\text{momentum diffusivity}}{\text{molecular diffusivity}} = \frac{\mu/\rho}{D_{AB}} = \frac{\nu}{D_{AB}}$$

Table 3.3 of B K Dutta:

(i) Laminar flow through a circular tube: $Re \leq 2100$

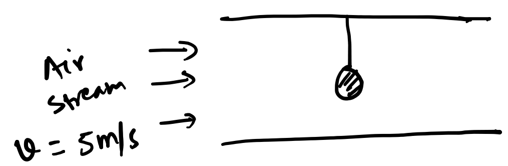
$$Sh = \frac{K_L d}{D} = 1.62\left[(Re)(Sc)(d/L)\right]^{1/3}$$

(ii) Turbulent flow through a tube: $4000 \leq Re \leq 60,000$

$0.6 \leq Sc \leq 3000$

$$Sh = 0.023\,(Re)^{0.83}(Sc)^{0.33}$$

Ex: 3.3 of B K Dutta



1) $T = 45^\circ C$; $P = 1$ atm

2) $t = 0$, Diameter of naphthalene ball = 1cm

3) Sublimation pressure of naphthalene @ $45^\circ C$ = 0.8654 mm Hg

4) $D_{AB} = 6.92 \times 10^{-6}\ m^2/s$

$\rho_{naphthalene}$ @ $45^\circ C$ = 1140 kg/m^3

$\rho_{air} = 1.1\ kg/m^3$; $\mu_{air} = 1.92 \times 10^{-5}\ kg/m.s$

Q: Time required for the diameter of the ball to reduce by half.

Assume, the following correlation holds in this case:

$$Sh = 2 + 0.6\,(Re)^{0.5}(Sc)^{0.33}$$

Solution : Naphthalene ← component A
Air ← Component B.

$$Re = \frac{(2r)\rho v}{\mu} = \frac{r(2)(1.1)(5)}{1.92\times10^{-5}} = 5.73\times10^{5} r$$

$$Sc = \frac{\mu/\rho}{D_{AB}} = \frac{1.92\times10^{-5}/1.1}{6.92\times10^{-6}} = 2.522$$

$$Sh = 2 + 0.6(Re)^{0.5}(Sc)^{0.33}$$

$$\boxed{Sh = 2 + 618\, r^{0.5}}$$

This case is similar to the case of diffusion of A through non-diffusing B.

$$Sh = \frac{K_G P_{BM} RT(2r)}{P D_{AB}} = \frac{K_G(0.08317)(318)(2r)}{6.92\times10^{-6}}$$

$$Sh = 7.644\times10^{6} K_G r$$

$$7.644\times10^{6} K_G r = 2 + 618\, r^{0.5}$$

$$K_G = \frac{2.616\times10^{-7}}{r} + \frac{8.085\times10^{-5}}{\sqrt{r}}$$

Mass Balance :

← $K_G \Delta P = K_G(P_{AS} - 0)$

$$-\frac{d}{dt}\left(\frac{4}{3}\pi r^3 \frac{\rho}{M}\right) = \text{Area} \times \text{Flux} = 4\pi r^2 \times K_G(P_{AS} - 0)$$

$$\Rightarrow \quad -\frac{dr}{dt} = \frac{3.3867\times10^{-11}}{r} + \frac{1.0467\times10^{-8}}{\sqrt{r}}$$

$t: 0 \rightarrow t_1$

$r = r_0 \rightarrow r_0/2$