

# Mass Transfer.

→ Mass transfer refers to movement of chemical species from high concentration region towards a low concentration one relative to other chemical species present in the medium.

\* ~~Analogy~~ <sup>Similarities</sup> between Heat & Mass Transfer:-

1) HT takes place when temp. gradient exists in a medium until temp. becomes uniform.

Mass Transfer takes place when a concentration gradient of one or more chemical species exists & it continues until conc. of all species becomes uniform over the entire volume.

2) Conduct<sup>n</sup> HT → Molecular phenomenon.

& Thermal Conductivity → Mtel property.

Similarly,

Diffusion Mass Transfer → Molecular phenomenon.

Diffusion Coefficient → Property of particular combination of species & medium.

3) Convective HTC → Flow property depending on fluid flow properties & geometry.

Convective Mass Transfer Coeff → <sup>depends on</sup> Flow & geometrical parameters & they can be described by similar governing equations.

\* Differences bet<sup>n</sup> Heat & Mass Transfer:-

1). Mass diffusion rate depends on molecular size of diffusing species compared to medium size in HT.

2) Heat Conduct<sup>n</sup> in its pure state, does not deal with any medium velocity. But pure mass diffusion deals with bulk velocity of medium.

3). In HT, boundary conditions may involve specified temp., specified heat flux, convection or radiation boundary, & their treatment is rather simple.

→ On other hand, in mass transfer, boundary may involve diff. phases, interphase such as condensation, evaporation, adsorption, chemical reaction etc. This makes boundary conditions much more complex.

### \* Convective Mass Transfer:-

$$\text{Heat Convect}^n = \frac{\text{Heat Conduct}^n}{\text{conduct}^n} + \frac{\text{Bulk fluid motion}}{\text{motion}}$$

→ Convective mass transfer involves diffusion of fluid with bulk movement of other fluid or diffusion bet<sup>n</sup> 2 immiscible moving fluid. It is the situation analogous to convection HT.

→ Convective MT is classified into :- Free Convection MT & Forced Convection MT.

→ In Free Mass Convection, Conc. gradient changes density of fluid, which may be acted upon by buoyancy force.

for eg:- Evaporation of Alcohol, Gasoline etc

→ In Force Mass Convection, one fluid is moving with appropriate velocity over the other.

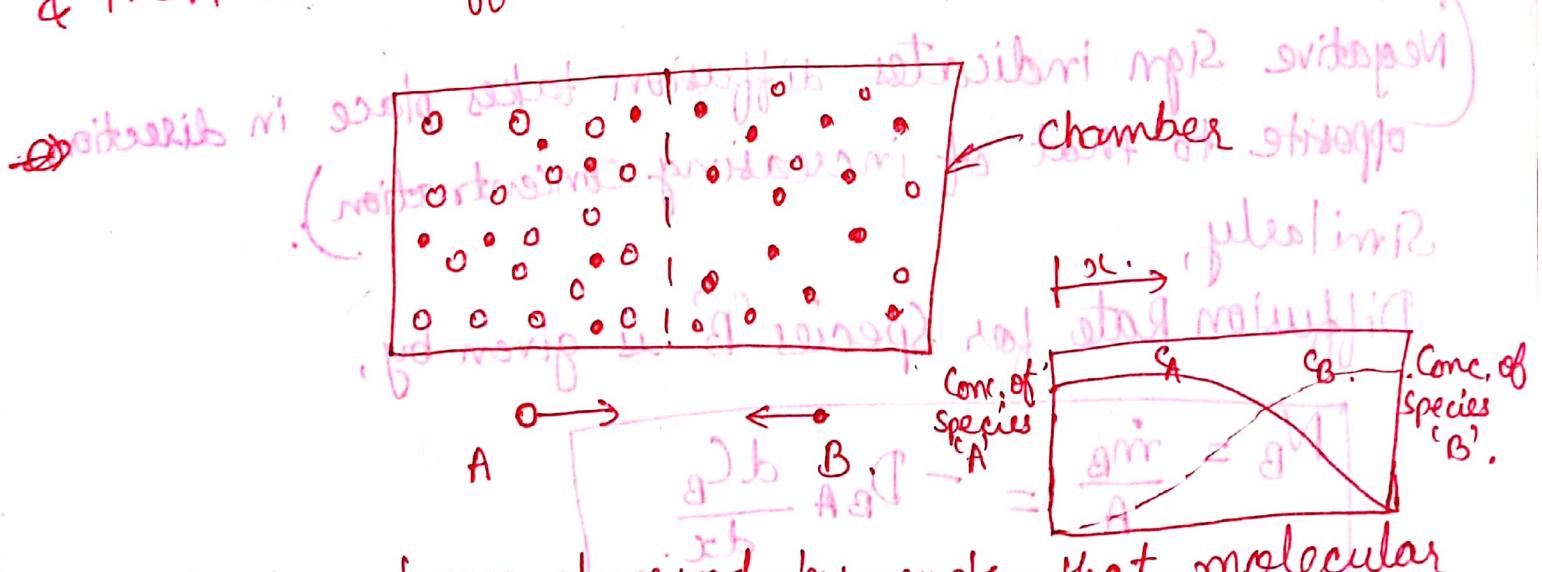
for eg:- Evaporation of Water in Ocean, Cooling tower or exhaust gas of an automobile is forced to pass over catalytic converter

→ Fluid flow may be laminar or turbulent. If fluid flow is laminar, then all of transport bet<sup>n</sup> surface & moving fluid will be by molecular means.

→ If fluid flow is turbulent, there will be physical movement of lumps of fluid across streamlines, transported by eddies present. Properties of these eddies may be 10 times larger than molecular values. Therefore mass transfer by forced convection is larger than that of free convection.

## \* \* Fick's Law :-

→ To understand "Mass Diffusion" (a transport process originating from molecular activity), Consider a chamber in which 2 different gas species 'A' & 'B', at same temp. & pressure are initially separated by partition. Left compartment has high conc. (i.e. more molecules per unit volume) of gas A (open circles) whereas right compartment is rich in gas B (dark circles). When partition wall is removed, ~~then~~ a driving potential comes into existence which tends to equalize concentration difference. Mass transfer by diffusion will be in direction of decreasing concentration & subsequently there will be net transport of species 'A' to the right & of species 'B' to the left. After sufficiently long period, equilibrium conditions prevail i.e. uniform conc. of species 'A' & 'B' are achieved & then mass diffusion ceases.



→ It has been observed by expts. that molecular diffusion is governed by Fick's Law, which is expressed as,

$$N_A = \frac{\dot{m}_A}{A} = -D_{AB} \frac{dC_A}{dx}$$

where  
 Diffusion flux.  $\rightarrow$   
 diffusion coefficient

$\dot{m}_A$  = Mass flow rate of species 'A' by diffusion, kg/sec.  
 $A$  = Area through which mass is flowing,  $m^2$

$N_A = \frac{\dot{m}_A}{A}$  = Mass flux of Species 'A'. (ie, Amount of species 'A' that is transferred per unit time & per unit area 'I' to direct" of transfer, ~~kg/m²~~  $kg/m^2\text{sec}$ .

$D_{AB}$  = Diffusion Coefficient, or Mass Diffusivity for binary mixture of species 'A' & 'B',  $m^2/\text{sec}$ .

$C_A$  = Concentration of molecules per unit volume of species 'A',  $\text{kg}/\text{m}^3$ .

$\frac{dC_A}{dx}$  = Concentration gradient for species 'A',  $\text{kg}/\text{m}^3$ .

Note:-

(Negative Sign indicates diffusion takes place in direction opposite to that of increasing concentration).

Similarly,

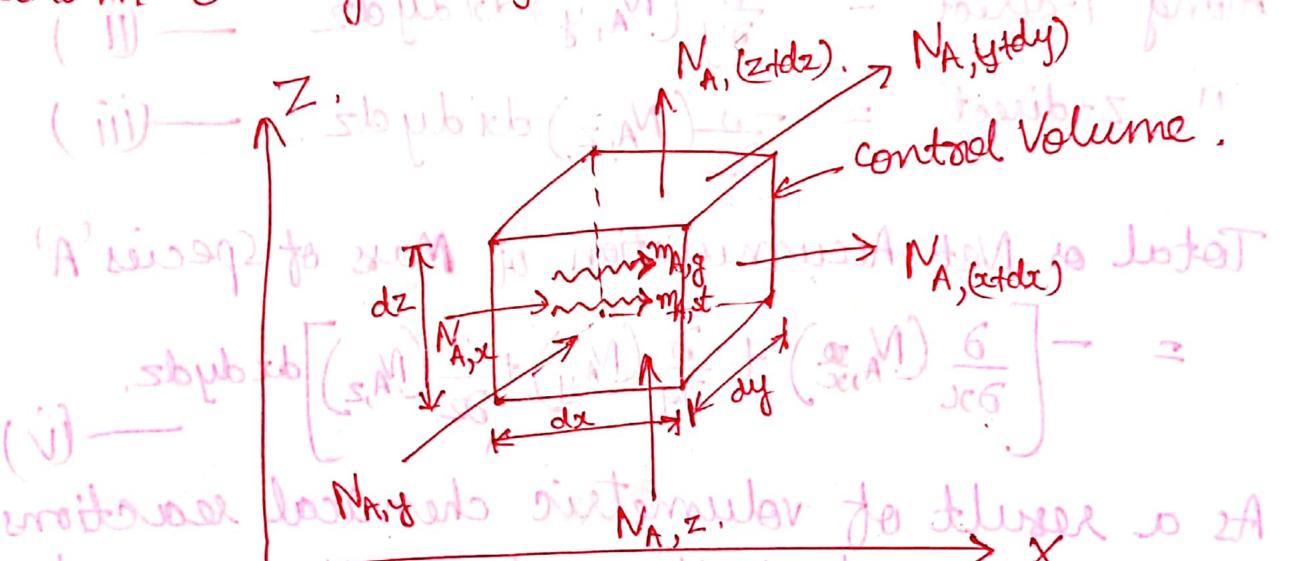
Diffusion Rate for Species 'B' is given by,

$$N_B = \frac{\dot{m}_B}{A} = -D_{BA} \frac{dC_B}{dx}$$

Diffusion Coefficient ( $D$ ) for 'B' is dependent on  $D_{BA}$ , temp., pressure & nature of components of the system.

## \* General Mass Diffusion Equation in Stationary Media :-

→ Consider a homogeneous medium consisting of binary mixtures of species 'A' & 'B'. Let the medium be stationary (i.e., mass avg. velocity or molar avg. velocity of mixture is zero) & mass transfer occurs only by diffusion. Now consider a differential control volume  $dx dy dz$  as shown in fig. Mass balance of species 'A' diffusing through C.V in stationary medium 'B' is given by:



written below the diagram: "written for diffusion of  $2A$  &  $B$  from left, mass diff. & transport process. Also, consider both mixture 'A' & 'B' for calculation, so changes of form

$$(V) \rightarrow \text{mass of } A \text{ in } (x, y, z) = p_A M$$

Along  $x$ -direction: - loss of  $A$  =  $\frac{p_A M}{A} (N_A, x \cdot dy dz)$

Mass influx at left face =  $N_A, x \cdot (dy dz)$ .

Mass efflux at right face =  $N_A, (x+dx) \cdot (dy dz)$

$$\rightarrow \text{if mass of } A \text{ in } (x, y, z) = N_A, x \cdot (dy dz) = [N_A, x \cdot (dy dz)] + \frac{\partial}{\partial x} (N_A, x) dy dz$$

Accumulation of gas 'A' in  $x$ -direct =  $-\frac{\partial}{\partial x} (N_{A,x}) dx dy dz$  — (i)

Similarly, Along  $y$ -direct =  $-\frac{\partial}{\partial y} (N_{A,y}) dy dz$  — (ii)

"  $z$ -direct" =  $-\frac{\partial}{\partial z} (N_{A,z}) dz$  — (iii)

Total or Net Accumulation of Mass of Species 'A'

$$= - \left[ \frac{\partial}{\partial x} (N_{A,x}) + \frac{\partial}{\partial y} (N_{A,y}) + \frac{\partial}{\partial z} (N_{A,z}) \right] dx dy dz. — (iv)$$

As a result of volumetric chemical reactions occurring throughout the medium, there may be generation of species 'A' within control volume, which may be expressed as,

$$m_{A,g} = N_{A,g} \cdot (dx dy dz) — (v)$$

(where)  $N_{A,g}$  = Rate of increase of mass of species 'A' due to chemical reactions per unit volume of mixture, =  $\text{kg/m}^3 \text{s}^{-1}$

Thus, equation (iv) & (v) together serves to increase mass concentration of species 'A'. This increase is reflected by time rate of change in mass concentration of species A in C.V & is

$$\frac{dN_A}{dt} = V \cdot n_A \cdot \frac{\partial C_A}{\partial x} \cdot dx dy dz — (vi)$$

$$[sbb_{x,y} + sbb_{y,z}] - (sbb_{x,y})_{ref} =$$

(58)

Now from Mass Balance, ~~(i) + (ii) + (iii) + (iv) + (v) = (vi)~~

$$\Rightarrow - \left[ \frac{\partial}{\partial x} (N_{A,x}) + \frac{\partial}{\partial y} (N_{A,y}) + \frac{\partial}{\partial z} (N_{A,z}) \right] dx dy dz + N_{A,g} \cdot (dx dy dz) = \frac{\partial C_A}{\partial x} \cdot (dx dy dz) \quad (ii)$$

$\Rightarrow$  Dividing b.s by  $dx dy dz = \cancel{x} \rightarrow 0 = \frac{\partial C_A}{\partial x}$

$$- \left[ \frac{\partial}{\partial x} (N_{A,x}) + \frac{\partial}{\partial y} (N_{A,y}) + \frac{\partial}{\partial z} (N_{A,z}) \right] + N_{A,g} = \frac{\partial C_A}{\partial x} \quad (iii)$$

Now, from Fick's Law of Diffusion,

$$\boxed{N_A = \frac{m}{A} = D_{AB} \left( \frac{\partial C_A}{\partial x} \right)} \quad (iv)$$

$\therefore$  Eq<sup>n</sup> (vii) will reduce  $\boxed{(m)_{\text{out}} - (m)_{\text{in}} = M}$

$$\Rightarrow D_{AB} \frac{\partial^2 C_A}{\partial x^2} + D_{AB} \frac{\partial^2 C_A}{\partial y^2} + D_{AB} \frac{\partial^2 C_A}{\partial z^2} + N_{A,g} = \frac{\partial C_A}{\partial x} \quad (vii)$$

$\therefore$  Dividing b.s by  $D_{AB}$

$$\Rightarrow \boxed{\frac{\partial^2 C_A}{\partial x^2} + \frac{\partial^2 C_A}{\partial y^2} + \frac{\partial^2 C_A}{\partial z^2} + \frac{N_{A,g}}{D_{AB}} = \frac{\partial C_A}{\partial x}} \quad (viii)$$

Above eq<sup>n</sup> is analogous to Heat Conduction Equation.