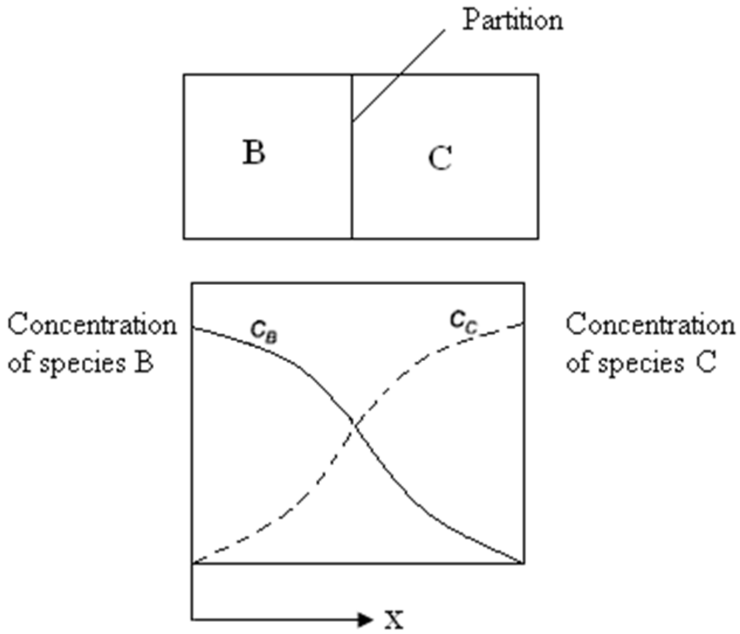
FDE 307
Mass Transfer and Unit Operations

THEORY OF DIFFUSION

- Molecular diffusion occurs without macroscopic mass motion or mixing. Dissolving of sugar in a cup of tea without stirring can be a good example to this kind of diffusion.
- Diffusion can be discussed for both steady-state and transient conditions. First, we will consider steady state diffusion, where the concentrations at any point do not change with time.

Fick's Law of Diffusion

- Let's consider a chamber which contains a mixture of two gases (B, C) and divided into two volumes by a partition in the middle. The schematic representation of the chamber is given in Figure below.



The schematic representation of Fick's law of diffusion for a binary mixture

- Initially the volume B is rich in species B and the volume C is rich in species C. If the partition between chambers is removed, molecules of B would diffuse to the right (in the direction of decreasing concentration of B) and the molecules of C would diffuse to the left. After sufficient time has elapsed, equilibrium conditions would be achieved (uniform concentrations of B and C would be attained and there would be no more mass diffusion). This can be explained by Fick’s law of diffusion.

- Fick’s law relates the mass flux by diffusion to the concentration gradient. Diffusion mass flux of a species through a medium is proportional to the concentration gradient. The Fick’s law can be stated as;

$$J_B = -D_{BC} \frac{dC_B}{dx}$$

where J_B (molar flux of component B) (kgmol/m^{2}s) is the number of moles of ‘B’ diffusing perpendicular to area A per unit time, D_{BC} is diffusion coefficient or mass diffusivity (m^2/s) of B into C, C_B is the mole concentration of ‘B’(moles/m^3) and x is distance.

Steady state equimolar counter diffusion in liquids

$$N_{Ax} = \underbrace{X_A(N_{Ax} + N_{Bx})}_{\text{convective transport term}} - \underbrace{CD_{AB}\frac{dX_A}{dx}}_{\text{diffusive transport term } (J_A)}$$

- Due to equimolar counter diffusion of A and B, the convective term is zero. Equation simplifies to;

$$N_{Az} = -D_{AB}\frac{dC_A}{dz}$$

Molecular diffusion through a stagnant liquid film

- The case of equimolar diffusion can be observed rarely in liquids, while molecular diffusion through a stagnant or non-diffusing liquid film is a more frequent case. In such a case N_B is equal to zero.

- **Example** A stagnant film of ethanol (A)–water (B) solution with a thickness of 2 mm is at 273 K. The film is in contact at one surface with an organic solvent in which ethanol is soluble but water is insoluble (N_B =0). The concentration of ethanol at one side of the film (point 1) is 16.8 % (w/w), and the density of the solution at this point is 972.8 kg/m^3. The concentration of ethanol and density of the solution at the other side (point 2) are 6.8 % (w/w) and 988.1 kg/m^3. If the diffusivity of ethanol is 0.74x10^{-9}m^2/s, calculate the flux with an assumption of steady state.