CHE 318 Lecture 08

Steady State Mass Transfer: More Examples

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Recap

- Mass transfer equations in other geometries
  - Use M.B. for $\overline{N}_A$, not N_A
  - Be careful with the coordinate system (sphere? cylinder?)
- Solving examples with pseudo steady state assumption

Learning Outcomes

(Continue from Lecture 07) After today's lecture, you will be able to:

- **Solve** P.S.S problems in spherical coordinates
- **Recall** difference between steady and unsteady state solutions
- **Analyze** time-dependent concentration profiles for U.S.S situations.

P.S.S Examples (continued)

Example 1: Diffusion Through Stagnant B with Changing Path Length

Adapted from Geankoplis 6.2-3

Water vapor diffuses through a stagnant gas in a narrow vertical tube, dry air is constantly blown at the top of tube.
At time t, the liquid level is a distance z from the tube top (i.e., the diffusion path length is z). As diffusion proceeds, the liquid level drops slowly, so z increases with time. The liquid has density ρ_A, and molecular weight M_A

1) Derive an expression for the time t_F required for the level to drop such that the diffusion path length changes from $z = z_0$ at $t = 0$ to $z = z_F$ at $t = t_F$.

Example 1: solutions

> **Tip**
>
> 1. Use pseudo steady-state assumption
> 2. N_A change over time!

Answer

$$t_F = \frac{\rho_A (z_F^2 - z_0^2) R T p_{Bm}}{2 D_{AB} M_A p_T} \frac{1}{(p_{A1} - p_{A2})}$$

Example 2: Determine D_{AB} Through Evaporation

Adapted from Griskey 10-2

Sample setup as example 4, a vertical tube of diameter $D = 0.01128$ m contains a liquid volatile species A (chloropicrin, CCl_3NO_2) evaporating into stagnant air (B) at 1 atm. The gas-phase diffusion of A occurs through the air column above the liquid surface.

At $t = 0$, the distance from the tube top to the liquid surface is $z_0 = 0.0388$ m, after $t = 1$ day, the distance is $z_1 = 0.0412$ m.

- Vapor pressure at the interface: $p_{A1} = 3178.3$ Pa
- Liquid density: $\rho_A = 1650$ kg/m^3
- Molecular weight: $M_A = 164.39$ kg/kmol

1) Use your expression from example 4, determine the binary diffusivity D_{AB} of A in air.

Example 2: solutions

> **Tip**
>
> Pseudo steady state solution and assuming $N_A =$ const solution differ very little. Why?

Answer:

1. Pseudo-steady state: $D_{AB} = 8.56 \times 10^{-6}$ m^2/s
2. N_A constant: $D_{AB} = 8.75 \times 10^{-6}$ m^2/s (+2.2% error)

Example 3: P.S.S For Diffusion Through Sphere

Adapted from Geankoplis Ex 6.2-4

A sphere of naphthalene having a radius of 2.0 mm is suspended in a large volume of still air at 318 K and 1.01325×10^5 Pa (1 atm). The surface temperature of the naphthalene can be assumed to be at 318 K and its vapor pressure at 318 K is 0.555 mm Hg. The D_AB of naphthalene in air at 318 K is 6.92×10^{-6} m^2/s.

1. Calculate the rate of evaporation of naphthalene from the surface.
2. Write the expression for the time t_F to evaporate a sphere from radius r_0 to r_F. The solid density for naphthalene is ρ and molecular weight is M_A.
3. What is the t_F value when the sphere is completely evaporated?

Example 3: solutions

> Tip
>
> Similar setup as example 5. N_A is time-dependent

Answer:

1) $N_A = 9.68 \times 10^{-8}$ kg mol/m^2/s
2) Expression for $t_F r = r_F$:

$$t_F(r = r_F) = \frac{\rho R T p_{Bm}}{2 M_A D_{AB} p_T} \frac{1}{(p_{A1} - p_{A2})} (r_0^2 - r_F^2)$$

3) Expression for $t_F(r = 0)$:

$$t_F(r = 0) = \frac{\rho R T p_{Bm} r_0^2}{2 M_A D_{AB} p_T} \frac{1}{(p_{A1} - p_{A2})}$$

Compare the solutions with Example 4. We can also measure the diffusivity of volatile organic molecules using the sphere evaporation method!

Summary

- Pseudo-steady state solutions to diffusion-evaporation problems
- We will discuss about unsteady state mass transfer next lecture!