CHE 318 Lecture 13

Introduction To Mass Transfer Coefficients

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2026-02-02

Recap

- Review of part I of mass transfer
- Mindmap in mass transfer part I
- Sample questions from previous exams

Learning Outcomes

After today's lecture, you will be able to:

- **Recall** motivations for study convective mass transfer
- **Describe** key assumptions in simplifying mass transfer coefficients in multiple phases and turbulent flow
- **Analyze** the units for mass transfer coefficients

Example Questions (Continued)

Long Answer Question 2

2. **(27 marks)** Carbon dioxide gas leakage from every tube in a process plant must be controlled and accounted for to meet regulatory requirements. CO_2 at 3.0 atm and 450K is flowing in a vulcanized rubber tube in your plant. This tube has a 5.0 mm inside diameter and 12.0 mm outside diameter. The leakage of CO_2 through this tube wall must be less than $3.75\text{x}10^{-3}$ kg mol CO_2/yr at steady state, where D_{AB} is $0.11\text{x}10^{-9}$ m^2/s, solubility is 0.9 m^3 (STP) solute/(m^3 (STP) solid x atm) and concentration related through 22.414.

    a. **(12 marks)** Derive the radial flux equation for a tube, showing all steps and assumptions.
    b. **(15 marks)** Determine the maximum tube length allowed

Long Answer Question 2 – Key Points

- Diagram (a cylinder with in/out diameter & length)
- Solid diffusion   EMCD-like equation (diffusion only)
- **DO NOT** write $N_A \propto 1/(d_2 - d_1)$!
- Steady state flux eq. in cylindrical coordinate
- Governing eq for cylindrical coordinate
- Use of $\overline{N}_A$ for steady state
- c_A from solubility

Long Answer Question 3

3. **(20 marks)** A tube is coated with enzyme that will convert 2 mols of A into 1 mol B within a flowing liquid solution that is in excess of B relative to A, rapidly and irreversibly. An initial concentration of c_{Ao} is in the tube, there is an inlet concentration c_{Ai}, a constant v_M, and an outlet concentration of c_A that varies with time (t). Please assume that the control volume is only within the liquid phase, that the flux in the axial direction is dominated by convection (i.e. $c_A v_M$), and that the reaction rate is dominated by the flux of A.

a. **(8 marks)** Fully label a schematic of the system

b. **(12 marks)** Derive overall unsteady state mass transfer equation for this system
   i. Note: do not integrate the Mass Balance Equation itself
   ii. Note: otherwise, simplify as much as possible

Long Answer Question 3 – Key Points

- Diagram (convection in axial / z-axis; diffusion in radial / r-axis)
- Mass balance in control volume
- Generation term link to flux-controlled consumption
- Flux boundary conditions in r-axis

Convective Mass Transfer

Remaining Questions From Unsteady State Mass Transfer

Our current knowledge cannot answer questions like this:

- If chemical species A is transferred between two difference phases, what is the concentration in each phase?

- How do we solve the mass transfer when c is not uniform? (See long answer question 2)
- What if fluid becomes turbulent?

What We Want To Solve In Part II: A Real Engineering Problem

You work in a pipeline maintenance team in Enbridge and need to remove a sticky, unwanted coating from the inner wall of a pipeline. There are a few design questions:

- Which flushing liquid works best?
  - solvent / water mixture
  - solubility of the coating
- How fast should the fluid flow?
  - required mean velocity v_m
- What concentration remains in the liquid?
  - outlet concentration of the contaminant
- How fast is the coating removed?
  - removal rate vs. v_m

What you want to report:

- Total volume of flushing liquid required
- Total flushing time to reach acceptable cleanliness

Mass Transfer Between Phases: Unsteady State Analysis

We will first look at the first problem, c_A between phase boundaries. This is something we *in theory* can solve using U.S.S. But what are the boundary conditions?

Question: a polymer membrane of thickness 2Δ contains a chemical with uniform concentration c_0 initially. At $t = 0$, it is suddenly submerged into a solution containing the same chemical with concentration c_1. The volume of liquid is very large that concentration remains c_1 far away from the membrane-liquid interface. Model the concentration profile $c(z)$ inside the membrane, and calculate the total chemical absorption rate.

Solving The Polymer Membrane Mass Transfer Problem

Use the standard procedure for the polymer phase, ignore convection inside

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

Initial conditions:

- Inside polymer $c_A(z, t = 0) = c_0$
- Outside polymer $c_A(z, t = 0) = c_1$

Boundary conditions?

- How do we know $c_A(z)$ at the interface?
- They can actually take any value!

Summary

In this lecture, we talked about

- Solving long-answer questions in midterm
- The difficulty of studying boundary problems in mass transfer
- The rise of equilibrium distribution coefficient K and mass transfer coefficient k

What To Learn Next

- We will introduce the **mass transfer coefficient** k as a general parameter for convective mass transfer

- How to use mass transfer coefficients for different phases (gas, liquid, solid)
- How convective fluid transport is expressed using coefficients
- How to perform mass transfer analysis based on transfer coefficients