

CHE 318 Lecture 19

Case Studies With Mass Transfer Coefficient

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Learning outcomes

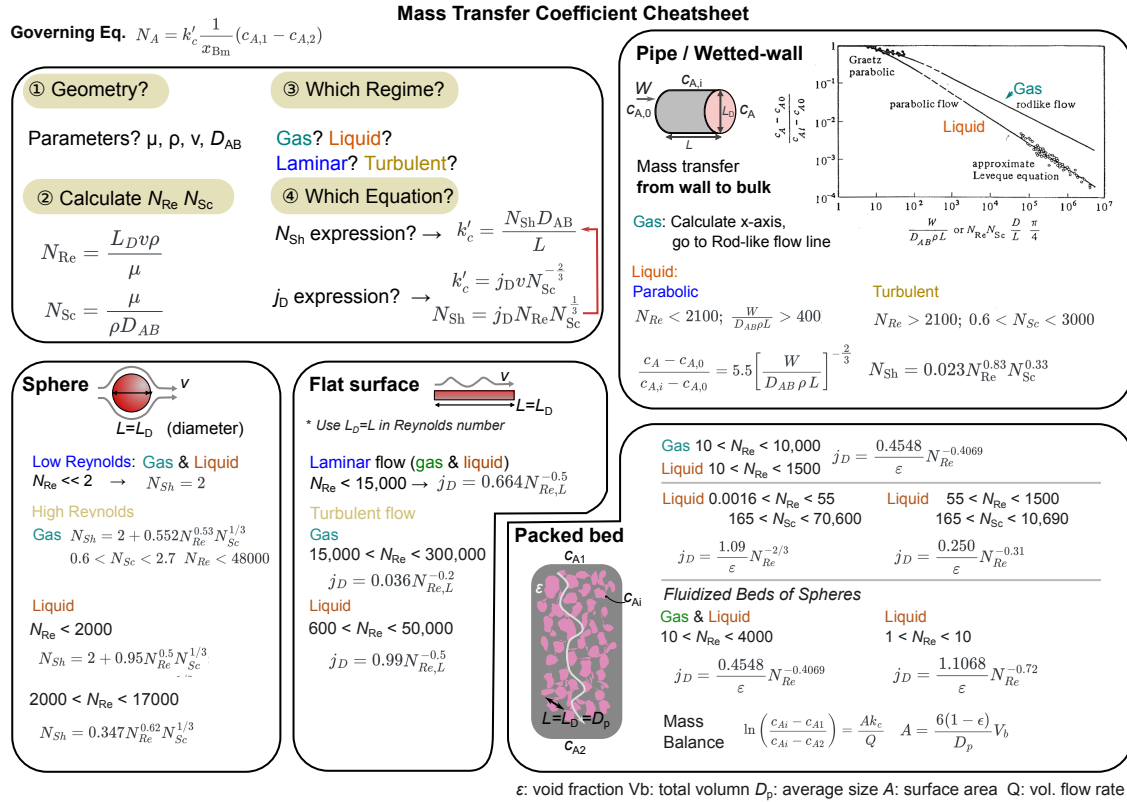
After this lecture, you will be able to:

- **Recall** the steps for convective mass transfer calculations using coefficient correlations and dimensionless numbers.
- **Apply** equations to calculate k'_c , outlet concentration, and flux for internal-flow problems.
- **Describe** how geometry and flow regime influence pipe mass transfer.

General procedure to calculate k'_c

- Dimensionless numbers solely from geometry and property: N_{Re} , N_{Sc}
- Dimensionless number having k'_c : N_{Sh}
- Link between them: j_D
- How to obtain j_D ?
 - Expression for different geometry / fluid flow
 - Use Table / Chart

Cheatsheet for mass transfer coefficient



ϵ : void fraction V_b : total volumn D_p : average size A : surface area Q : vol. flow rate

Figure 1: Cheatsheet for using dimensionless numbers with k'_c . Printed version distributed in class

Example 1: mass transfer for flow inside pipes

Problem 7.3.1: A tube is coated on the inside with naphthalene and has inside diameter of 20 mm & a total length of 1.10 m. Air at 318 K and average pressure of 101.3 kPa flows through the pipe with velocity of 0.8 m/s. Calculate the concentration of naphthalene at outlet

Physical properties: $D_{AB} = 6.92 \times 10^{-6} \text{ m}^2/\text{s}$, vapour pressure $p_{Ai} = 74.0 \text{ Pa}$. For air, $\mu = 1.932 \times 10^{-5} \text{ Pa} \cdot \text{s}$, $\rho = 1.114 \text{ kg}/\text{m}^3$

Flow inside pipe: chart

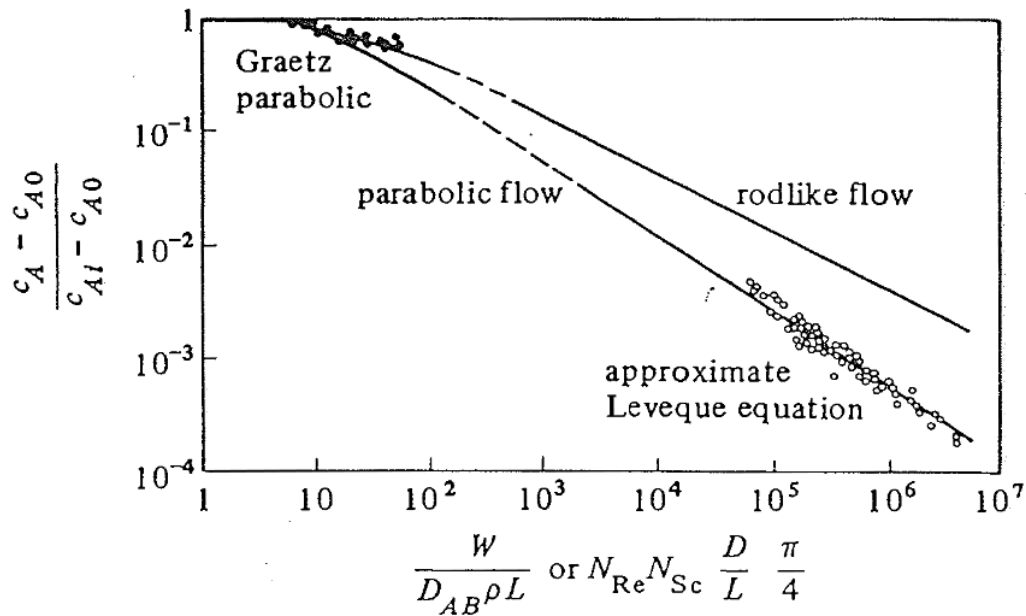


FIGURE 7.3-2. Data for diffusion in a fluid in streamline flow inside a pipe: filled circles, vaporization data of Gilliland and Sherwood; open circles, dissolving-solids data of Linton and Sherwood. [From W. H. Linton and T. K. Sherwood, *Chem. Eng. Progr.*, **46**, 258 (1950). With permission.]

Flow inside pipes: solution procedure

- Governing dimensionless quantity:

$$\frac{W}{D_{AB}\rho L} = N_{Re} N_{Sc} \frac{D}{L} \frac{\pi}{4} \quad (1)$$

$$= \frac{[\text{Total Forced Flow}](\text{kg/s})}{[\text{Total Diffusive Flow}](\text{kg/s})} \quad (2)$$

- If gas use the “rodlike flow” line
- If liquid, distinguish 2 cases
 - parabolic flow ($N_{Re} < 2100$; $\frac{W}{D_{AB}\rho L} > 400$)
 - turbulent flow ($N_{Re} > 2100$; $0.6 < N_{Sc} < 3000$)

Flow inside pipes: solution for liquid

Parabolic flow

$$\frac{c_A - c_{A,0}}{c_{A,i} - c_{A,0}} = 5.5 \left[\frac{W}{D_{AB} \rho L} \right]^{-\frac{2}{3}} \quad (3)$$

- c_A : exit concentration
- $c_{A,i}, c_{A,0}$: interface & inlet concentration
- W : flow rate in (kg/s)
- k'_c can be calculated by j_D

Turbulent flow

$$N_{Sh} = k'_c \left(\frac{D}{D_{AB}} \right) \quad (4)$$

$$= \frac{k_c p_{BM}}{P} \left(\frac{D}{D_{AB}} \right) \quad (5)$$

$$= 0.023 \left(\frac{\rho D v}{\mu} \right)^{0.83} \left(\frac{\mu}{\rho D_{AB}} \right)^{0.33} \quad (6)$$

$$= 0.023 N_{Re}^{0.83} N_{Sc}^{0.33} \quad (7)$$

- Similar to the j_D analog
- Just need N_{Re} and N_{Sc} to determine k'_c
- Characteristic length D is pipe diameter!

Review example 1: solution steps

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- Step 1: Calculate N_{Re} , N_{Sc} . Which regime?

Review example 1: solution steps

- Step 2: find normalized concentration on chart

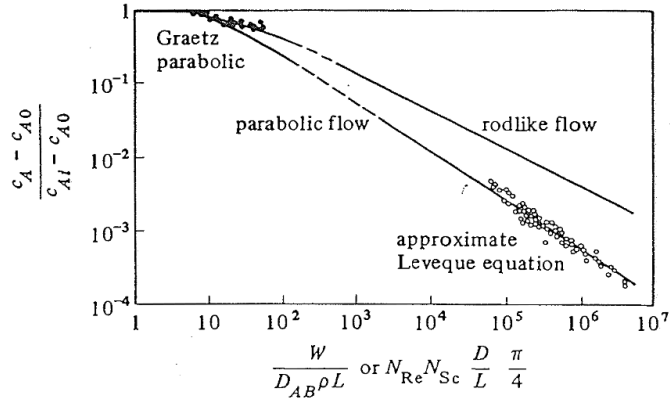


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Example 1: follow up

- 1) How will the outlet concentration change, if we double the gas velocity (i.e. $v_m = 1.6$ m/s)?
- 2) If gas-phase D_{AB} becomes smaller, how will the outlet concentration change?

Example 1-2: pipe mass transfer in liquid

Problem 7.3-2: Pure water at 26.1°C ($\rho = 996$ kg/m³, $\mu = 8.71 \times 10^{-4}$ Pa·s) flows at an average velocity of 0.0305 m/s through a tube of inside diameter 6.35 mm. The tube is 1.829 m long, and the last 1.22 m of the tube wall is coated with benzoic acid.

The solubility of benzoic acid in water is 0.02948 kg mol/m³, and the diffusivity of benzoic acid in water is 1.245×10^{-9} m²/s. For water, $\mu = 8.71 \times 10^{-4}$ Pa·s and $\rho = 996$ kg/m³. Calculate the cross-sectional average concentration of benzoic acid at the outlet.

Example 1-2: solution steps

- Step 1: calculate N_{Re} , N_{Sc} . Regime?
- Step 2: check the value $W/D_{AB}\rho L$. Able to use liquid formula?
- Step 3: insert into equations

Parabolic flow

$$\frac{c_A - c_{A,s}}{c_{A,i} - c_{A,s}} = 5.5 \left[\frac{W}{D_{AB} \rho L} \right]^{-\frac{2}{3}} \quad (8)$$

Turbulent flow

$$N_{Sh} = k'_c \left(\frac{D}{D_{AB}} \right) \quad (9)$$

$$= \frac{k_c p_{BM}}{P} \left(\frac{D}{D_{AB}} \right) \quad (10)$$

$$= 0.023 \left(\frac{\rho D v}{\mu} \right)^{0.83} \left(\frac{\mu}{\rho D_{AB}} \right)^{0.33} \quad (11)$$

$$= 0.023 N_{Re}^{0.83} N_{Sc}^{0.33} \quad (12)$$

Example 1-2: results

i Note

- Use $L_D = 6.35$ mm for N_{Re}
- Please use $L = 1.22$ m for N_{Sh} !

The following numbers were obtained

- $N_{Re} = 221.4$
- $N_{Sc} = 702.41$
- $W = 9.616 \times 10^{-4}$ kg / s
- x-axis: 634.4
- Use the **liquid laminar** equation to get $c_{A,out} = 2.196 \times 10^{-3}$ kg mol/m³

Summary

- Learn to use the coefficient chart to solve for different systems
- Case study of transport in a tube geometry