Convection Mass Transfer

Mass Transfer coefficients

Convective mass transfer parameters

Convective Mass Transfer

Introduction

Mass transfer by convection involves the transport of material between a boundary surface (such as solid or liquid surface) and a moving fluid or between two relatively immiscible, moving fluids.

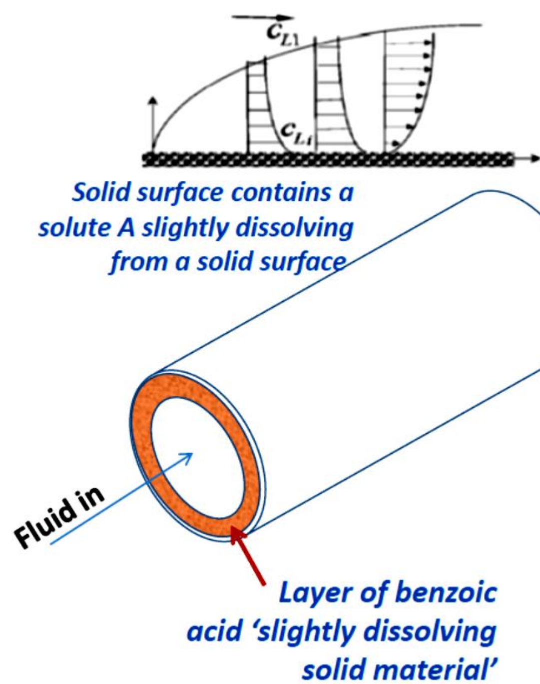
Cases of convection Mass Transfer

- Mass transfer takes place only in a single phase either to or from a phase Boundary.
  Example: 'sublimation of naphthalene (solid form) into the moving air'
- Mass transfer takes place in the two contacting phases as in extraction and absorption.

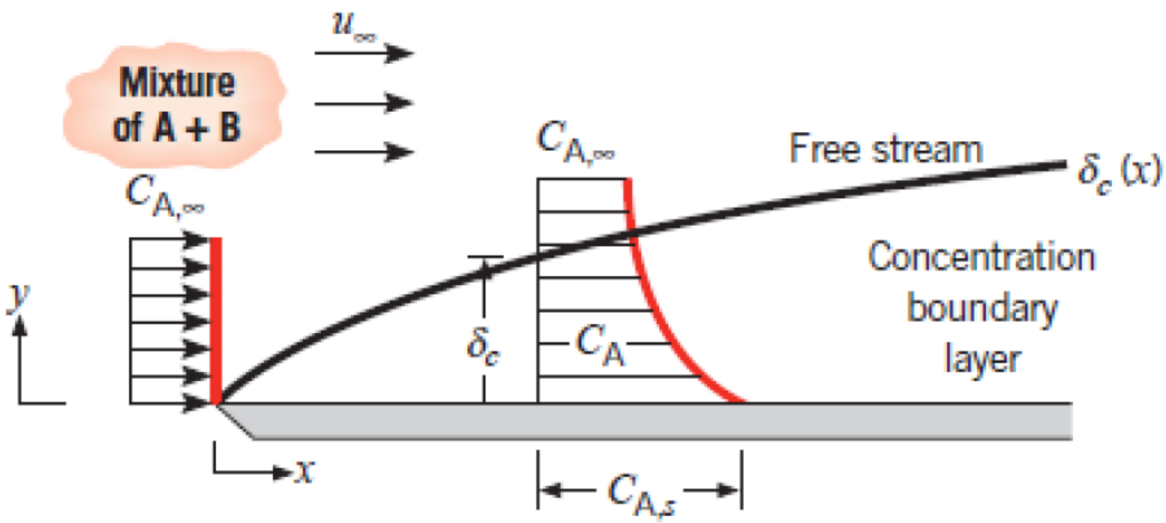
How can we obtain a convection mass transfer flow?

There are two possible ways to obtain a fluid in a convective flow:

1. Passing a fluid by another fluid 'immiscible' ;or
2. Passing a fluid over a solid surface.

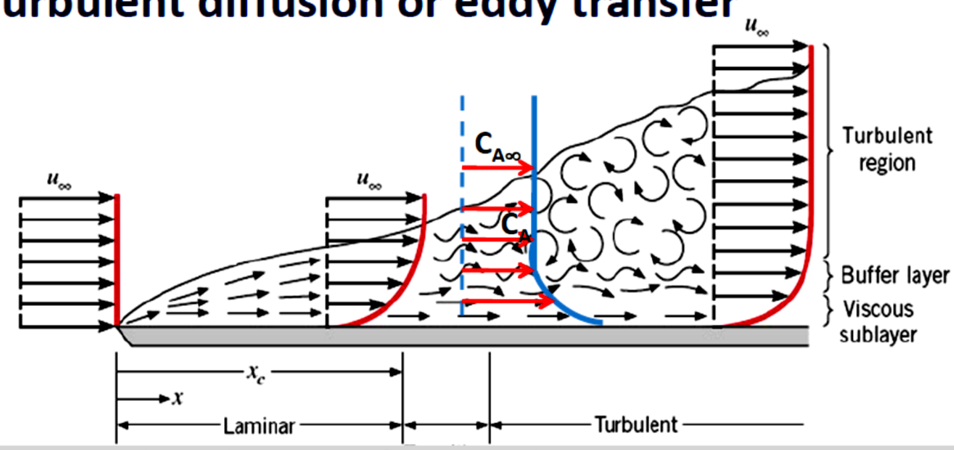


Species concentration boundary layer development on a flat plate



Vapor (species A) in gas (species B). !!! H_2O in air over the surface of ocean

Turbulent diffusion or eddy transfer

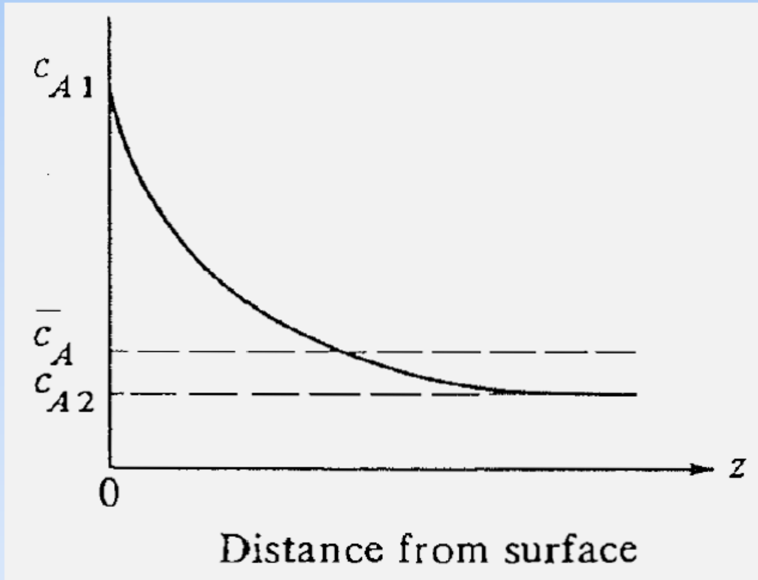


Three regions of mass transfer can be visualized. In the first, which is adjacent to the surface, a thin viscous sublayer film is present. Most of the mass transfer occurs by molecular diffusion, since few or no eddies are present. A large concentration drop occurs across this film as a result of the slow diffusion rate.

The transition or buffer region is adjacent to the first region. Some eddies are present and the mass transfer is the sum of turbulent and molecular diffusion. There is a gradual transition in this region from the transfer by mainly molecular diffusion at the one end to mainly turbulent at the other end.

In the *turbulent region* adjacent to the buffer region, most of the transfer is by turbulent diffusion, with a small amount by molecular diffusion. The concentration decrease is very small here since the eddies tend to keep the fluid concentration uniform.

Concentration profile for turbulent mass transfer from a surface to a fluid



Definition of mass-transfer coefficient

- For turbulent convection mass transfer Fick's Law can be extended and written as (at constant c)

mass eddy diffusivity

$$J_A^* = -(D_{AB} + \varepsilon_M)\frac{dc_A}{dz} \qquad (1)$$

Integrating between point 1 and 2 and use the avg. value of ε_M ;($\bar{\varepsilon}_M$)

$$J_{A1}^* = \frac{D_{AB} + \bar{\varepsilon}_M}{z_2 - z_1}(c_{A1} - c_{A2}) \Rightarrow J_{A1}^* = k_c'(c_{A1} - c_{A2}) \qquad (2)$$

Path is usually not known

convective mass-transfer coefficient k_c'

experimental mass-transfer coefficient

similar to the convective heat-transfer coefficient h

Flux based on surface area A_1 since the cross-sectional area mar vary

Since the cross-sectional area may vary.

Mass-transfer coefficient for equimolar counterdiffusion

- Similar to molecular diffusion

$$N_A = -c(D_{AB} + \varepsilon_M)\frac{dx_A}{dz} + x_A(N_A + N_B) \quad (3)$$

where $N_A = -N_B$

- Integrating at steady state, and rearrangement,

$$N_A = k'_c(c_{A1} - c_{A2}) \quad (4)$$

- Since concertation, c_A takes different definitions "units", so coefficient k'_c can be written in several ways:

Gas phase $$N_A = k'_c(c_{A1} - c_{A2}) = k'_G(p_{A1} - p_{A2}) = k'_y(y_{A1} - y_{A2}) \quad (5)$$

Liquid phase $$N_A = k'_c(c_{A1} - c_{A2}) = k'_L(c_{A1} - c_{A2}) = k'_x(x_{A1} - x_{A2}) \quad (6)$$

Mass Transfer coefficient for A diffusing through stagnant, nondiffusing B

- In this case, $N_B = 0$, again as before integrate the following equation

$$N_A = -c(D_{AB} + \varepsilon_M)\frac{dx_A}{dz} + x_A(N_A + N_B) \quad (7)$$

- The result is

$$N_A = \frac{k'_c}{x_{BM}}(c_{A1} - c_{A2}) = k_c(c_{A1} - c_{A2}) \quad (8)$$

- Rewriting using other units

Gas phase $$N_A = k_c(c_{A1} - c_{A2}) = k_G(p_{A1} - p_{A2}) = k_y(y_{A1} - y_{A2}) \quad (9)$$

Liquid phase $$N_A = k_c(c_{A1} - c_{A2}) = k_L(c_{A1} - c_{A2}) = k_x(x_{A1} - x_{A2}) \quad (10)$$

Summary

TABLE 7.2-1. *Flux Equations and Mass-Transfer Coefficients*

Flux equations for equimolar counterdiffusion

Gases: $N_A = k'_c(c_{A1} - c_{A2}) = k'_G(p_{A1} - p_{A2}) = k'_y(y_{A1} - y_{A2})$

Liquids: $N_A = k'_c(c_{A1} - c_{A2}) = k'_L(c_{A1} - c_{A2}) = k'_x(x_{A1} - x_{A2})$

Flux equations for A diffusing through stagnant, nondiffusing B

Gases: $N_A = k_c(c_{A1} - c_{A2}) = k_G(p_{A1} - p_{A2}) = k_y(y_{A1} - y_{A2})$

Liquids: $N_A = k_c(c_{A1} - c_{A2}) = k_L(c_{A1} - c_{A2}) = k_x(x_{A1} - x_{A2})$

Conversions between mass-transfer coefficients

Gases:

$$k'_c c = k'_c \frac{P}{RT} = k_c \frac{p_{BM}}{RT} = k'_G P = k_G p_{BM} = k_y y_{BM} = k'_y = k_c y_{BM} c = k_G y_{BM} P$$

Liquids:

$$k'_c c = k'_L c = k_L x_{BM} c = k'_L \rho/M = k'_x = k_x x_{BM}$$

(where ρ is density of liquid and M is molecular weight)

Units of mass-transfer coefficients

	SI Units		*Cgs Units*	*English Units*
k_c, k_L, k'_c, k'_L	m/s		cm/s	ft/h
k_x, k_y, k'_x, k'_y	$\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{mol frac}}$		$\frac{\text{g mol}}{\text{s} \cdot \text{cm}^2 \cdot \text{mol frac}}$	$\frac{\text{lb mol}}{\text{h} \cdot \text{ft}^2 \cdot \text{mol frac}}$
k_G, k'_G	$\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{Pa}}$ (preferred)	$\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{atm}}$	$\frac{\text{g mol}}{\text{s} \cdot \text{cm}^2 \cdot \text{atm}}$	$\frac{\text{lb mol}}{\text{h} \cdot \text{ft}^2 \cdot \text{atm}}$

Summary + Example

In Sum

All the mass-Transfer Coefficients can be related to each other as given in the previous table.

For example:

Equating Eq. (8) WITH Eq.(10)

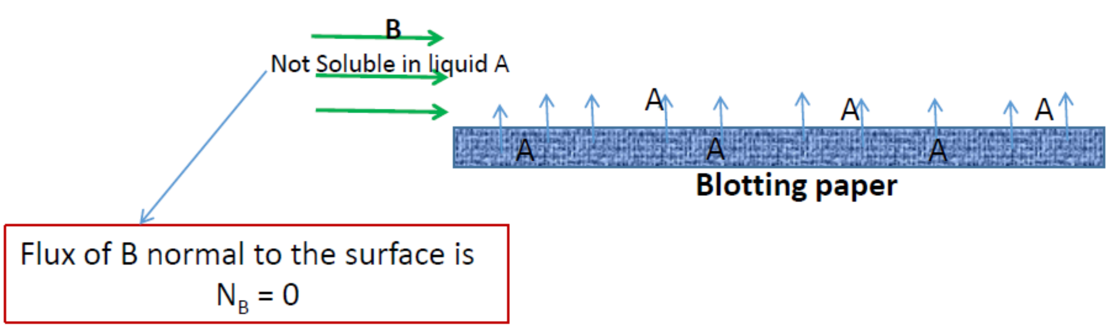
$$N_A = \frac{k'_c}{x_{BM}}(c_{A1} - c_{A2}) = k_x(x_{A1} - x_{A2}) = k_x\left(\frac{c_{A1}}{c} - \frac{c_{A2}}{c}\right)$$

$$\therefore \quad \frac{k'_c}{x_{BM}} = \frac{k_x}{c}$$

Example

A large volume of pure gas B at 2 atm pressure is flowing over a surface from which pure A is vaporizing. The liquid A completely wets the surface, which is a blotting paper. Hence, the partial pressure of A at the surface is the vapor pressure of A at 298 K, which is 0.20 atm. The k'_y has been estimated to be 6.78×10^{-5} kg mol/s · m^2 · mol frac. Calculate N_A, the vaporization rate, and also the value of k_y and k_G.

Schematic



This is the case of A diffusing through B

B is stagnant, nondiffusing. Now;

$p_{A1} = 0.2$ atm and $p_{A2} = 0$ in the pure gas B. Also, $y_{A1} = p_{A1}/P = 0.20/2.0 = 0.10$ and $y_{A2} = 0$. We can use Eq. (9) with mole fractions.

"We have gas phase mass transfer through B stagnant"

Solution

$$N_A = k_y(y_{A1} - y_{A2}) \qquad (9)$$

From table

$$k_y\, y_{BM} = k'_y \qquad (11)$$

y_{BM} is similar to x_{BM}

Or

$$y_{BM} = \frac{y_{B2} - y_{B1}}{\ln (y_{B2}/y_{B1})}$$

$$y_{B1} = 1 - y_{A1} = 1 - 0.10 = 0.90$$

$$y_{B2} = 1 - y_{A1} = 1 - 0 = 1.0$$

$$\therefore \quad y_{BM} = \frac{1.0 - 0.90}{\ln (1.0/0.90)} = 0.95$$

From Eq. (11)

$$k_y = \frac{k'_y}{y_{BM}} = \frac{6.78 \times 10^{-5}}{0.95} = 7.138 \times 10^{-5} \text{ kg mol/s} \cdot \text{m}^2 \cdot \text{mol frac}$$

From Table

$$k_G\, y_{BM}\, P = k_y\, y_{BM}$$

Hence, solving for k_G and substituting knowns,

$$k_G = \frac{k_y}{P} = \frac{7.138 \times 10^{-5}}{2 \times 1.01325 \times 10^5 \text{ Pa}} = 3.522 \times 10^{-10} \text{ kg mol/s} \cdot \text{m}^2 \cdot \text{Pa}$$

$$k_G = \frac{k_y}{P} = \frac{7.138 \times 10^{-5}}{2.0 \text{ atm}} = 3.569 \times 10^{-5} \text{ kg mol/s} \cdot \text{m}^2 \cdot \text{atm}$$

To obtain the flux, use eq. (9)

$$N_A = k_y(y_{A1} - y_{A2}) = 7.138 \times 10^{-5}(0.10 - 0)$$

$$= 7.138 \times 10^{-6} \text{ kg mol/s} \cdot \text{m}^2$$

Also,

$$p_{A1} = 0.20 \text{ atm} = 0.20(1.01325 \times 10^5) = 2.026 \times 10^4 \text{ Pa}$$

Using Eq. (9) again,

$$N_A = k_G(p_{A1} - p_{A2}) = 3.522 \times 10^{-10}(2.026 \times 10^4 - 0)$$
$$= 7.138 \times 10^{-6} \text{ kg mol/s} \cdot \text{m}^2$$

$$N_A = k_G(p_{A1} - p_{A2}) = 3.569 \times 10^{-5}(0.20 - 0)$$
$$= 7.138 \times 10^{-6} \text{ kg mol/s} \cdot \text{m}^2$$

Note that in this case, since the concentrations were dilute, y_{BM} is close to 1.0 and k_y and k'_y differ very little.

SIGNIFICANT PARAMETERS IN CONVECTIVE MASS TRANSFER

- The molecular diffusivities of the three transport phenomena are:

$$\textit{momentum diffusivity}, \nu = \mu/\rho$$
$$\textit{thermal diffusivity}, \alpha = \frac{k}{\rho c_p}$$
$$\textit{mass diffusivity}, D_{AB}$$

➢ **Schmidt number Sc**

$$\frac{\text{momentum diffusivity}}{\text{mass diffusivity}} = \text{Sc} \equiv \frac{\nu}{D_{AB}} = \frac{\mu}{\rho D_{AB}}$$

The Schmidt number plays a role in convective mass transfer analogous to that of the Prandtl number in convective heat transfer

➢ ***Lewis number Le***

$$\frac{\text{thermal diffusivity}}{\text{mass diffusivity}} = \text{Le} \equiv \frac{k}{\rho c_p D_{AB}}$$

- The Lewis number is encountered when a process involves the simultaneous convective transfer of mass and energy.

❖ ***Look***!! $\text{Sc} \equiv \frac{\nu}{D_{AB}} = \frac{\mu}{\rho D_{AB}} = \frac{\text{momentum diffusivity}}{\text{mass diffusivity}}$

This number gives a measure of the relative effectiveness of momentum in the velocity B.L. and mass transport by diffusion in the concentration B.L.

For Sc ≈ 1.0 , this means momentum transfer = mass transfer. See the next slide!

Sc interpretation !!