People's Democratic Republic Of Algeria
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
Abdelhafid Boussouf University Center - Mila
Institute of Science & Technology
Process Engineering Department

Introduction to Transport Phenomena

Course Notes

By: Dr. BOUTI Mohamed

Academic Year: 2023 - 2024

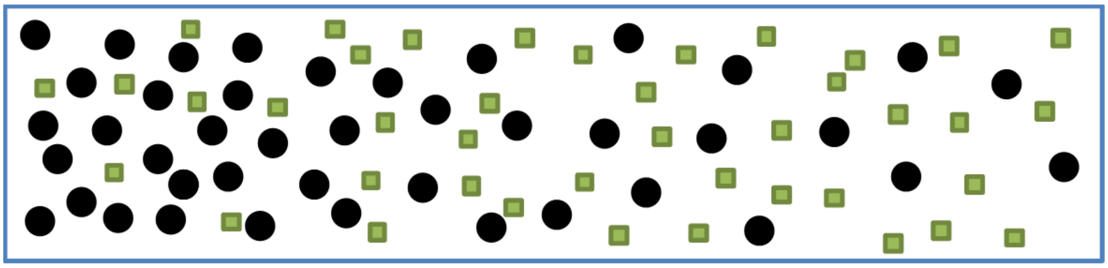
Chapter 3

Mass Transfer

REMINDER:

1. Mass Transfer:

Mass transfer is the net movement of a component in a mixture from one location to another location where the component exists at a **different concentration**.



2. Modes of mass transfer:

- *Diffusion*:

Transfer of molecules by **random motion** from high concentration to low concentration.

- *Convection*:

The use of mechanical force or action to increase the rate of molecular diffusion is convection.

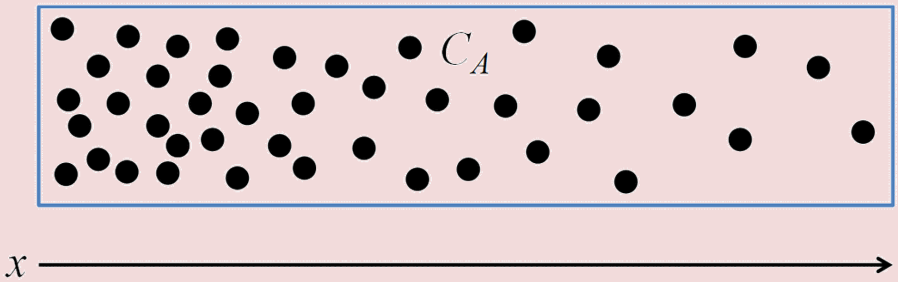
3. Concentration profiles :

A *concentration profile* is a sketch that indicates the magnitude of the concentration as a function of position **C =** $\boldsymbol{f(x)}$. This sketch is often superimposed on a process to indicate where these changes occur.

This is analogous to a velocity profile for fluid flow.

Exercise: *Concentration profile*

Based on the molecular distribution below, draw the concentration profile of species **A** as a function of $\boldsymbol{x}$:



Exercise: Quick questions

1. Mass transfer occurs because of gradient in what quantity?
    a. temperature
    b. pressure
    c. fluid flow
    d. concentration
2. The two main types of mass transfer are:
    a. diffusion and conduction
    b. convection and diffusion
    c. radiation and convection
    d. conduction and radiation

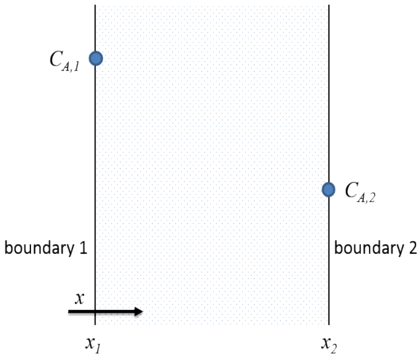
1. DIFFUSION

1.1. Describing diffusion quantitatively

Exercise: Diffusion

Suppose we have molecule **A** diffusing in a domain between boundary 1 and boundary 2, where $\mathbf{C_{A,1}}$ and $\mathbf{C_{A,2}}$ are held fixed.

What happens to $\mathbf{C_A}$ between boundary 1 and boundary 2 and what is the rate of diffusional mass transfer (*moles/time*) across some area **A**? Note that **A** represents an area ***y*** by ***z*** into the figure.



1.2. Fick's law of diffusion

$$\dot{N}_{A,x} = -D_{AB}\, A\, \frac{dc_A}{dx}$$

For a system in which there is pure diffusion only (no convection, no reactions, constant properties), the *concentration profile* is **linear**.

Thus, Fick's law can be approximated by

$$\dot{N}_{A,x} = -D_{AB}\, A\left(\frac{c_{A,2} - c_{A,1}}{x_2 - x_1}\right) = -D_{AB}\, A\left(\frac{\Delta c_A}{\Delta x}\right)$$

Hence, the driving potential for diffusional mass transfer is: $\mathbf{C_{A,2} - C_{A,1}}$.

In the above equations,

Variable	Definition	Typical units
$\dot{N}_{A,x}$	moles of species A transferred per unit time from location 1 to location 2	$\mathrm{mol/s}$
D_{AB}	the 'binary diffusivity' (or diffusion coefficient) of species A through medium B	$\mathrm{m^2/s}$
A	the 'face' area through which transfer occurs	$\mathrm{m^2}$
$c_{A,2} - c_{A,1}$	the difference in concentration between locations 2 and 1	$\mathrm{mol/m^3}$
$x_2 - x_1$	the distance between locations 2 and 1	m

Exercise: Fick's law

Why is there a minus sign in Fick's law?

Response:

The negative sign of the equation indicates that diffusion occurs in a direction opposite to that of the increasing concentration. Hence, diffusion occurs in the direction of decreasing concentration of the diffusing substance, and thus, the diffusion flux is a positive quantity.

1.3. The diffusion coefficient :

One of the big unknowns in Fick's equation above is the diffusion coefficient, $\mathbf{D_{AB}}$. The diffusion coefficient (or diffusivity) is **proportionality constant** between the molar flux due to molecular diffusion and the gradient in the concentration of the species (or the driving force for diffusion).

On a theoretical basis, the *diffusion coefficient* is proportional to the mean squared displacement divided by the time:

$$D \propto \frac{\langle x^2 \rangle}{t}$$

Properties will influence the diffusion coefficient of molecule **A** in solution **B**:
molecular size of **A** and/or **B**; molecular weight of **A** and/or **B**; temperature; pressure …etc.

Exercise:

What are some typical values of diffusion coefficients? Which coefficients will be largest?

- Gases?
- Liquids?
- Solids?

Substance *A*	Substance *B*	*T*, K	D_{AB} or D_{BA}, m²/s
Argon, Ar	Nitrogen, N_2	293	1.9×10^{-5}
Carbon dioxide, CO_2	Benzene	318	0.72×10^{-5}
Carbon dioxide, CO_2	Hydrogen, H_2	273	5.5×10^{-5}
Carbon dioxide, CO_2	Nitrogen, N_2	293	1.6×10^{-5}
Carbon dioxide, CO_2	Oxygen, O_2	273	1.4×10^{-5}
Carbon dioxide, CO_2	Water vapor	298	1.6×10^{-5}
Hydrogen, H_2	Nitrogen, N_2	273	6.8×10^{-5}
Hydrogen, H_2	Oxygen, O_2	273	7.0×10^{-5}
Oxygen, O_2	Ammonia	293	2.5×10^{-5}
Oxygen, O_2	Benzene	296	0.39×10^{-5}
Oxygen, O_2	Nitrogen, N_2	273	1.8×10^{-5}
Oxygen, O_2	Water vapor	298	2.5×10^{-5}
Water vapor	Argon, Ar	298	2.4×10^{-5}
Water vapor	Helium, He	298	9.2×10^{-5}
Water vapor	Nitrogen, N_2	298	2.5×10^{-5}

Substance *A* (Solute)	Substance *B* (Solvent)	*T*, K	D_{AB}, m²/s
Ammonia	Water	285	1.6×10^{-9}
Benzene	Water	293	1.0×10^{-9}
Carbon dioxide	Water	298	2.0×10^{-9}
Chlorine	Water	285	1.4×10^{-9}
Ethanol	Water	283	0.84×10^{-9}
Ethanol	Water	288	1.0×10^{-9}
Ethanol	Water	298	1.2×10^{-9}
Glucose	Water	298	0.69×10^{-9}
Hydrogen	Water	298	6.3×10^{-9}
Methane	Water	275	0.85×10^{-9}
Methane	Water	293	1.5×10^{-9}
Methane	Water	333	3.6×10^{-9}
Methanol	Water	288	1.3×10^{-9}
Nitrogen	Water	298	2.6×10^{-9}
Oxygen	Water	298	2.4×10^{-9}
Water	Ethanol	298	1.2×10^{-9}
Water	Ethylene glycol	298	0.18×10^{-9}
Water	Methanol	298	1.8×10^{-9}
Chloroform	Methanol	288	2.1×10^{-9}

Substance *A* (Solute)	Substance *B* (Solvent)	*T*, K	D_{AB}, m²/s
Carbon dioxide	Natural rubber	298	1.1×10^{-10}
Nitrogen	Natural rubber	298	1.5×10^{-10}
Oxygen	Natural rubber	298	2.1×10^{-10}
Helium	Pyrex	773	2.0×10^{-12}
Helium	Pyrex	293	4.5×10^{-15}
Helium	Silicon dioxide	298	4.0×10^{-14}
Hydrogen	Iron	298	2.6×10^{-13}
Hydrogen	Nickel	358	1.2×10^{-12}
Hydrogen	Nickel	438	1.0×10^{-11}
Cadmium	Copper	293	2.7×10^{-19}
Zinc	Copper	773	4.0×10^{-18}
Zinc	Copper	1273	5.0×10^{-13}
Antimony	Silver	293	3.5×10^{-25}
Bismuth	Lead	293	1.1×10^{-20}
Mercury	Lead	293	2.5×10^{-19}
Copper	Aluminum	773	4.0×10^{-14}
Copper	Aluminum	1273	1.0×10^{-10}
Carbon	Iron (fcc)	773	5.0×10^{-15}
Carbon	Iron (fcc)	1273	3.0×10^{-11}

2. MASS CONVECTION :

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

2.1. Newton's law of cooling

To quantify **the rate of mass transfer** owing to convection, we can use **Newton's law of cooling** (which also applies to *convective heat transfer*).

Newton's law of cooling for mass transfer:

$$\dot{N}_A = h_m\, A\, (c_{A,s} - c_{A,\infty})$$

Hence, the driving potential for convective mass transfer is: $\mathbf{C_{A,s} - C_{A,\infty}}$

In the above equations,

Variable	Definition	Typical units
$\dot{N}_{A,x}$	moles of species A transferred per unit time from the surface to the bulk fluid far from the surface	$\mathrm{mol/s}$
h_m	the mass transfer coefficient	$\mathrm{m/s}$
A	the area (cross section) through which transfer occurs	$\mathrm{m^2}$
$c_{A,s} - c_{A,\infty}$	the difference in concentration between the surface and bulk fluid	$\mathrm{mol/m^3}$