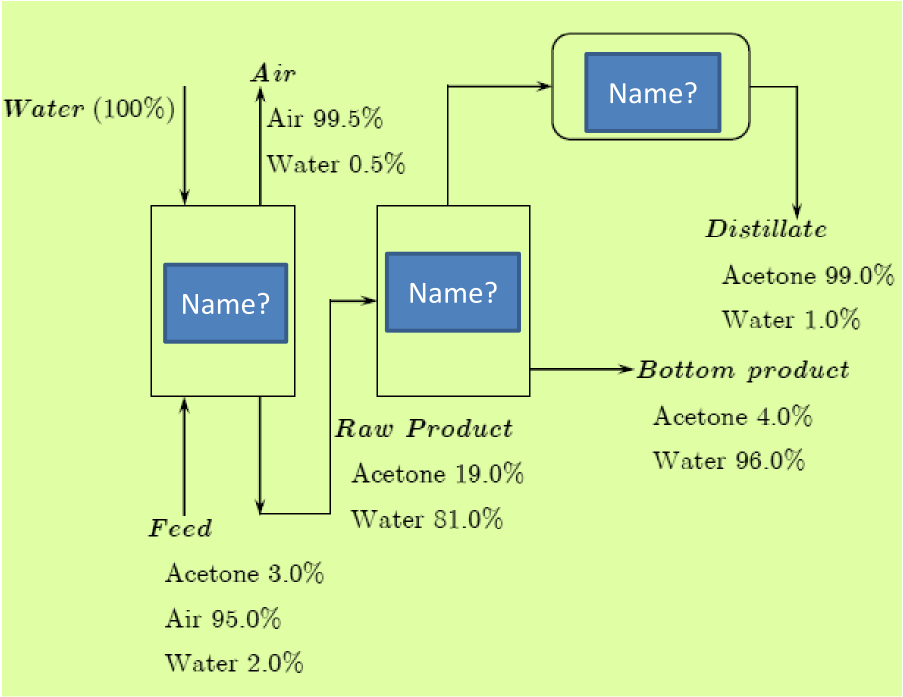
REVISION

Mass Transfer Course

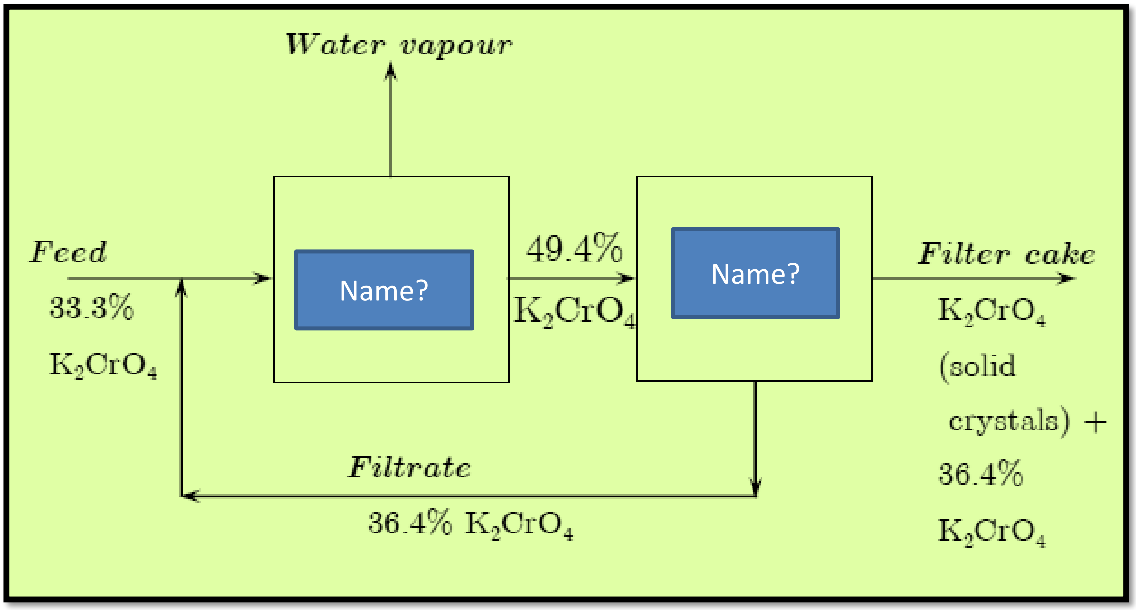
General Introduction

Why are we required to study mass transfer?



Example 1: The acetone recovery process

Example 2: The production of Potassium chromate, K_2CrO_4 crystals



Water vapour

Feed

33.3% K_2CrO_4

Name?

49.4% K_2CrO_4

Name?

Filter cake

K_2CrO_4 (solid crystals) + 36.4% K_2CrO_4

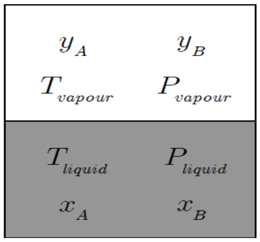
Filtrate

36.4% K_2CrO_4

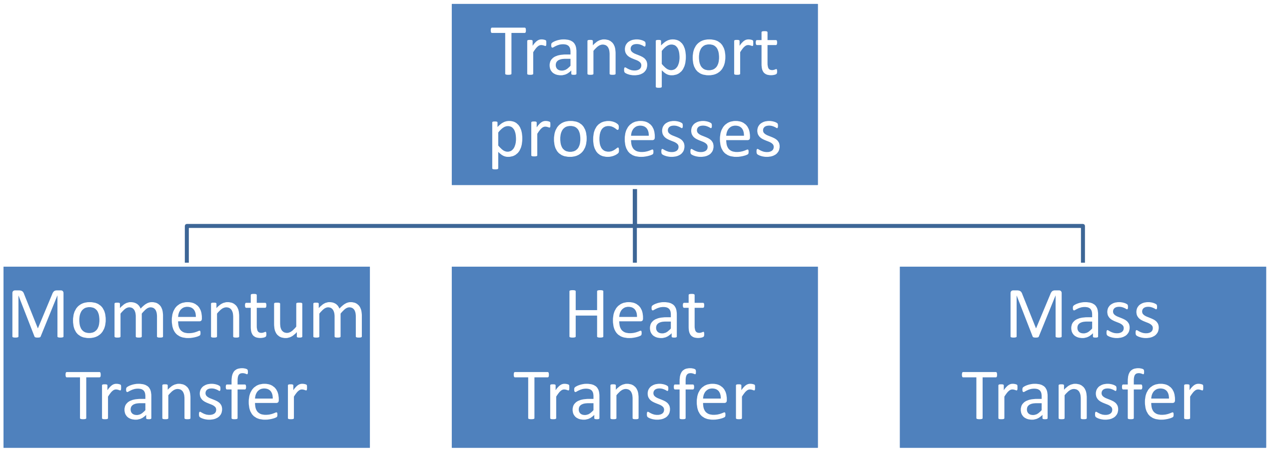
What is the **difference between equilibrium and steady state?**

- Consider Vapor-liquid equilibrium (VLE) of a binary mixture.
- From thermodynamic course 2 we know that at equilibrium.

$$T_{vapor} = T_{liquid}$$
$$P_{vapor} = P_{liquid}$$



- At equilibrium there are **no changes in any properties with time** ***and there are no differences, also in*** any properties, **within the system.**
- **At steady state** there are *no changes in any* properties *with time* ***only, implying that there*** may be differences in any properties within the system.



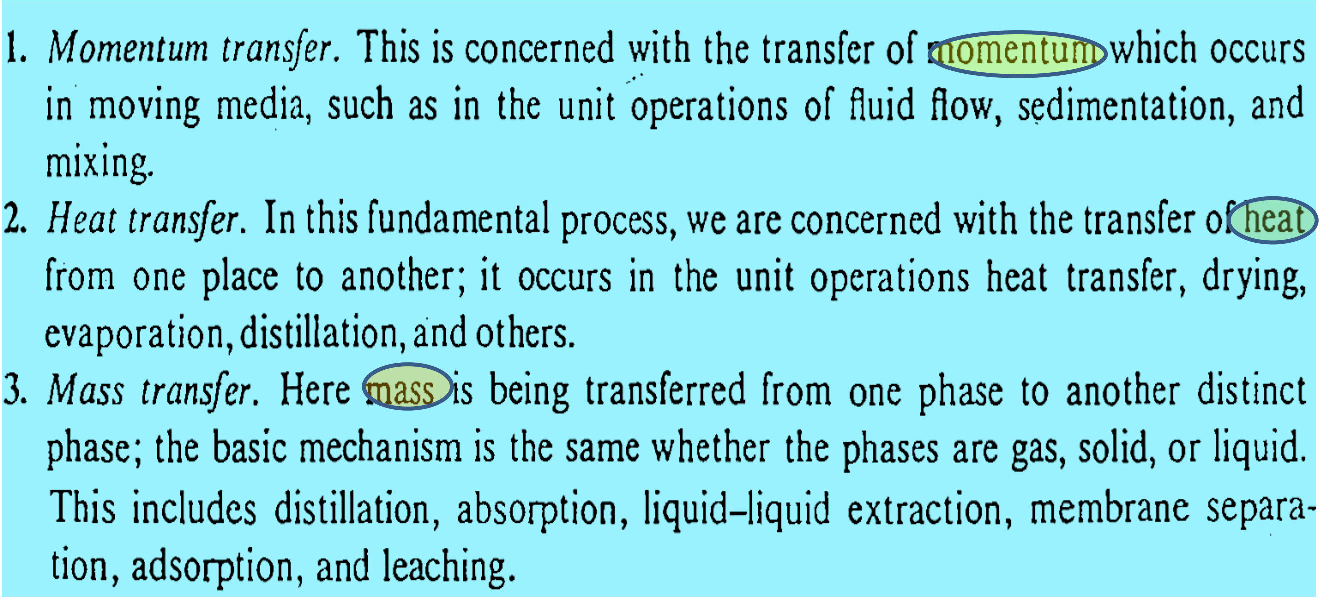
Transport processes

Momentum Transfer

Heat Transfer

Mass Transfer

Definitions



1. *Momentum transfer*. This is concerned with the transfer of momentum which occurs in moving media, such as in the unit operations of fluid flow, sedimentation, and mixing.
2. *Heat transfer*. In this fundamental process, we are concerned with the transfer of heat from one place to another; it occurs in the unit operations heat transfer, drying, evaporation, distillation, and others.
3. *Mass transfer*. Here mass is being transferred from one phase to another distinct phase; the basic mechanism is the same whether the phases are gas, solid, or liquid. This includes distillation, absorption, liquid–liquid extraction, membrane separation, adsorption, and leaching.

Definition

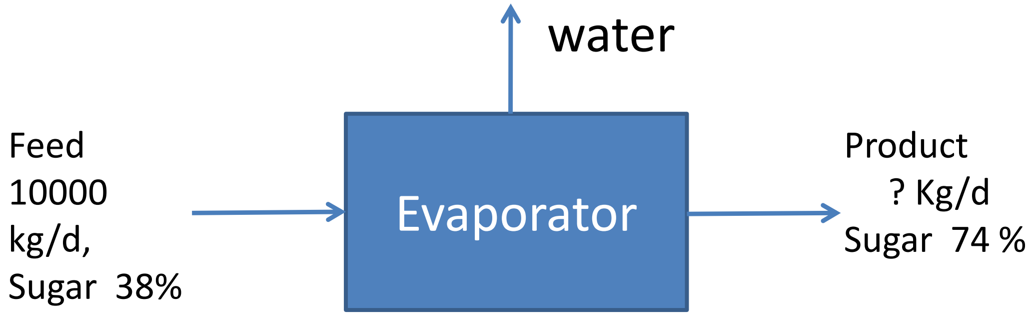
Industrial mass transfer operations utilize the transfer of one or more components of mixtures from one phase to another. The different process may be classified according to whether the phases are in gaseous, liquid or solid state

Phases	Processes
Gas-liquid	Absorption-stripping Distillation Humidification-drying
Liquid-liquid	Extraction
Gas-solid	Adsorption-desorption Drying
Liquid-solid	Leaching Adsorption-desorption Crystallization-dissolving

Problem 1

An evaporator is used to concentrate cane sugar solutions. A feed of 10000 kg/d of solution containing 38 wt% sugar is evaporated, producing a 74 wt% solution. Calculate the weight of solution produced and the amount of water removed.

Solution



water

Feed
10000
kg/d,
Sugar 38%

Evaporator

Product
? Kg/d
Sugar 74 %

mechanism of mass transfer

Depends upon the dynamics of the system in which it occurs:

1-Molecular Diffusion:

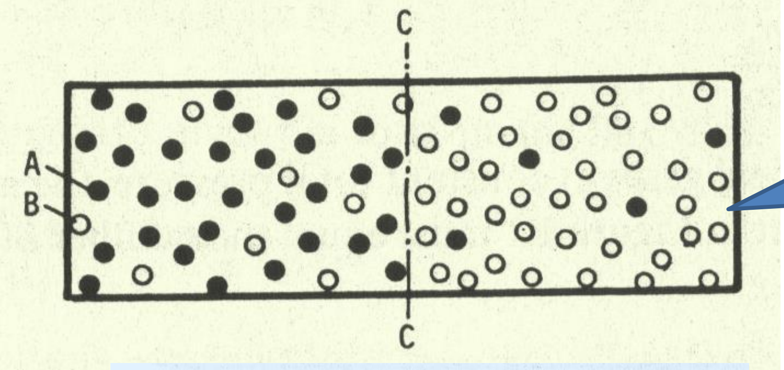
Random molecular motion in quiescent fluids

2- Convection:

transferred from a surface into a moving fluid, aided by the dynamic characteristics of the flow

The two mechanisms often act simultaneously. However, in the confluence of the two modes of mass transfer, one mechanism can dominate quantitatively so that approximate solutions involving only the dominant mode need be used.

Diffusion principle



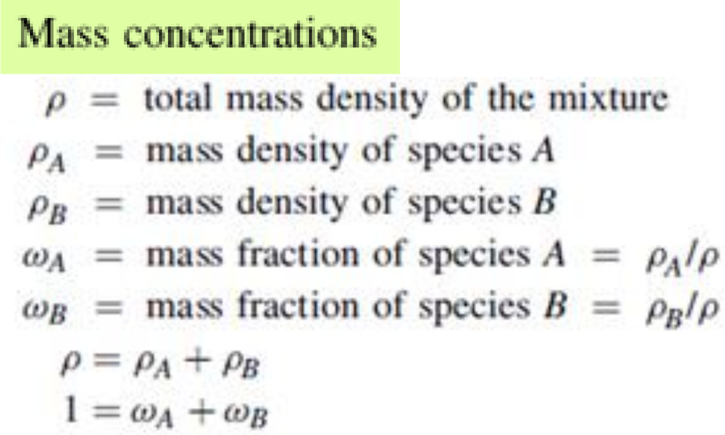
Molecules A and B confined in a box at constant pressure and temperature

Molecular diffusion

Flux

$$Flux = \frac{\text{Amount of diffusing substance}}{\text{area normal to the flow x time}}$$

Concentrations in a binary mixture of A and B



Mass concentrations

ρ = total mass density of the mixture

ρ_A = mass density of species A

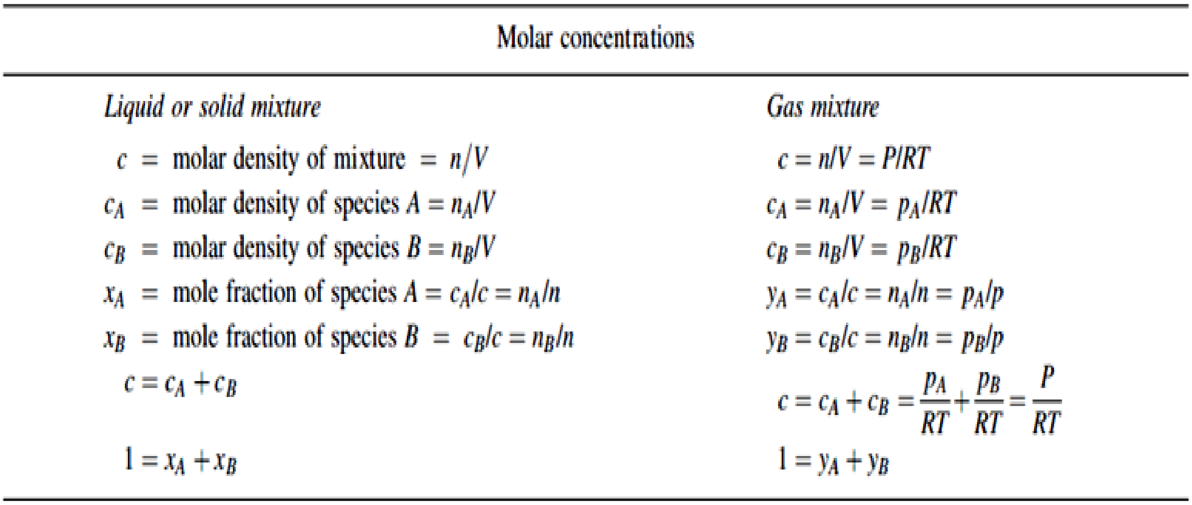
ρ_B = mass density of species B

ω_A = mass fraction of species A = ρ_A/ρ

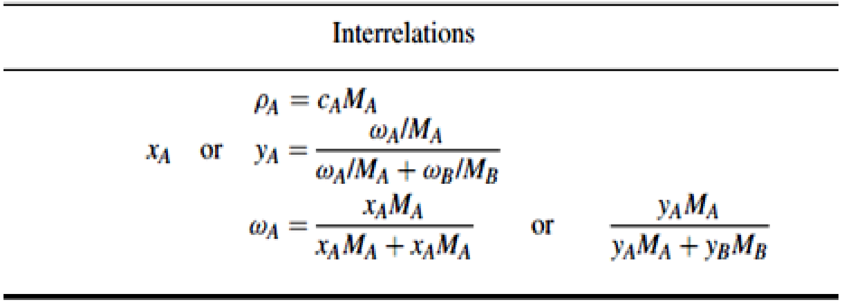
ω_B = mass fraction of species B = ρ_B/ρ

$$\rho = \rho_A + \rho_B$$

$$1 = \omega_A + \omega_B$$



Molar concentrations	
Liquid or solid mixture	*Gas mixture*
c = molar density of mixture $= n/V$	$c = n/V = P/RT$
c_A = molar density of species $A = n_A/V$	$c_A = n_A/V = p_A/RT$
c_B = molar density of species $B = n_B/V$	$c_B = n_B/V = p_B/RT$
x_A = mole fraction of species $A = c_A/c = n_A/n$	$y_A = c_A/c = n_A/n = p_A/p$
x_B = mole fraction of species $B = c_B/c = n_B/n$	$y_B = c_B/c = n_B/n = p_B/p$
$c = c_A + c_B$	$c = c_A + c_B = \frac{p_A}{RT} + \frac{p_B}{RT} = \frac{P}{RT}$
$1 = x_A + x_B$	$1 = y_A + y_B$



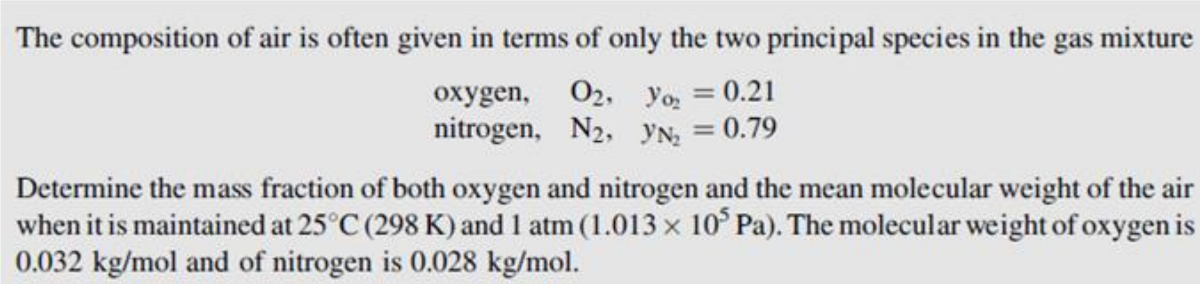
Interrelations

$$\rho_A = c_A M_A$$

$$x_A \quad \text{or} \quad y_A = \frac{\omega_A / M_A}{\omega_A / M_A + \omega_B / M_B}$$

$$\omega_A = \frac{x_A M_A}{x_A M_A + x_A M_A} \quad \text{or} \quad \frac{y_A M_A}{y_A M_A + y_B M_B}$$

Example 1



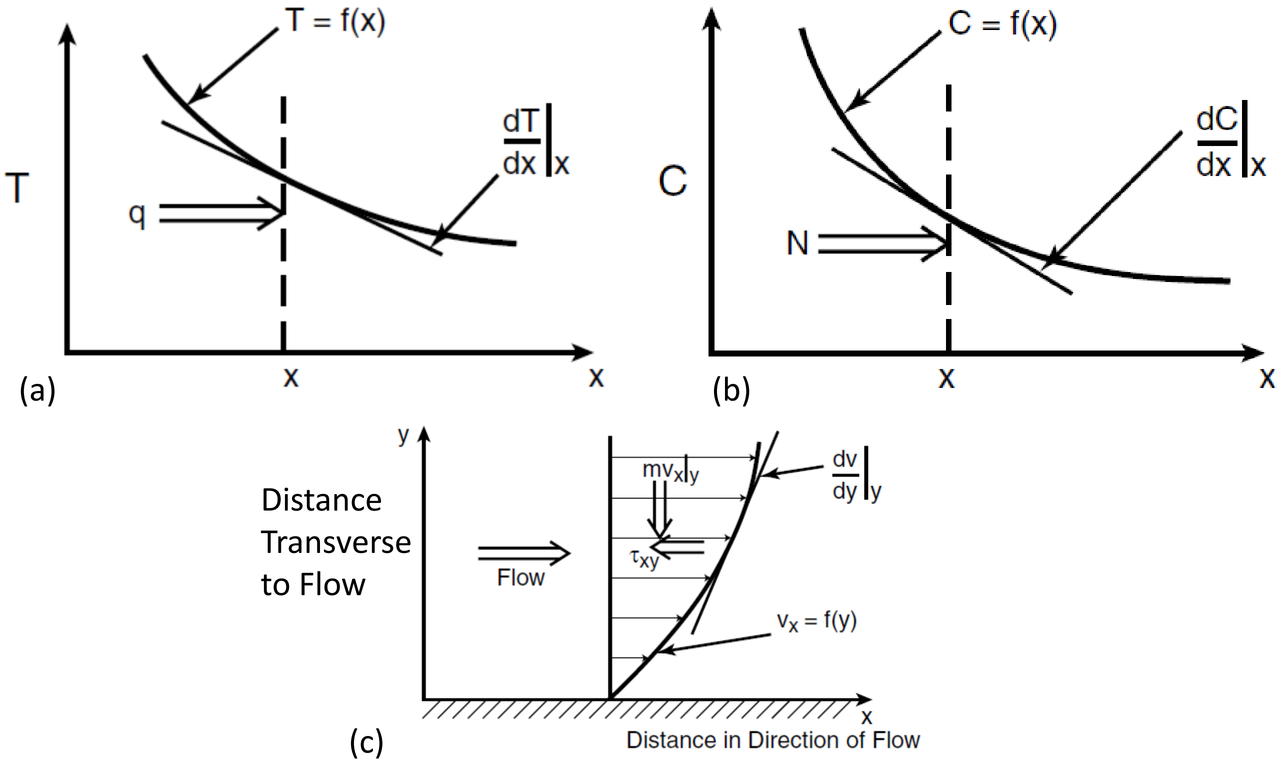
The composition of air is often given in terms of only the two principal species in the gas mixture

oxygen, O_2, $y_{O_2} = 0.21$
nitrogen, N_2, $y_{N_2} = 0.79$

Determine the mass fraction of both oxygen and nitrogen and the mean molecular weight of the air when it is maintained at 25°C (298 K) and 1 atm (1.013×10^5 Pa). The molecular weight of oxygen is 0.032 kg/mol and of nitrogen is 0.028 kg/mol.

Solution

Diffusive transport: (a) heat; (b) mass; (c) momentum.

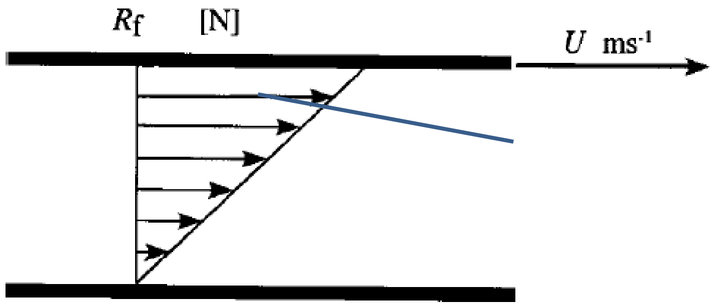


Three Fundamental Laws of Transport Phenomena

- **Newton’s Law of Viscosity**

$$\tau = \tau_w = R_f / A$$

$$\tau = -\mu \frac{du}{dy}$$

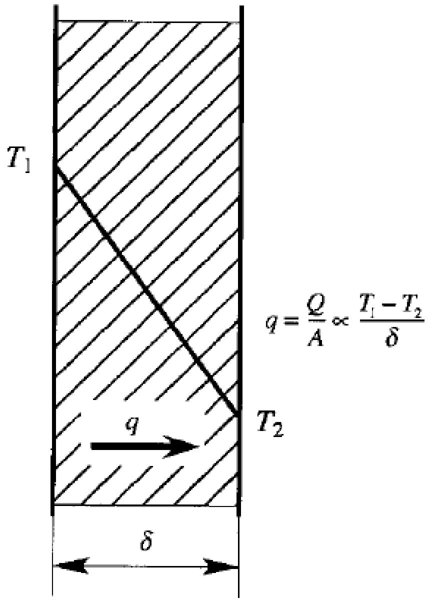


Flow of a viscous fluid between two parallel plates

where *A is the surface area of the plate [m2], y is the distance from the wall [m],* τ is the shear stress in the fluid [Pa], τ_w *(≅ Rf/A) is the shear stress at the wall* [Pa], and μ is the *viscosity [Pa s], which is one of the important physical properties* of the fluid

- **Fourier’s Law of Heat Conduction**

$$q = \frac{Q}{A} = -\kappa \frac{dT}{dy}$$

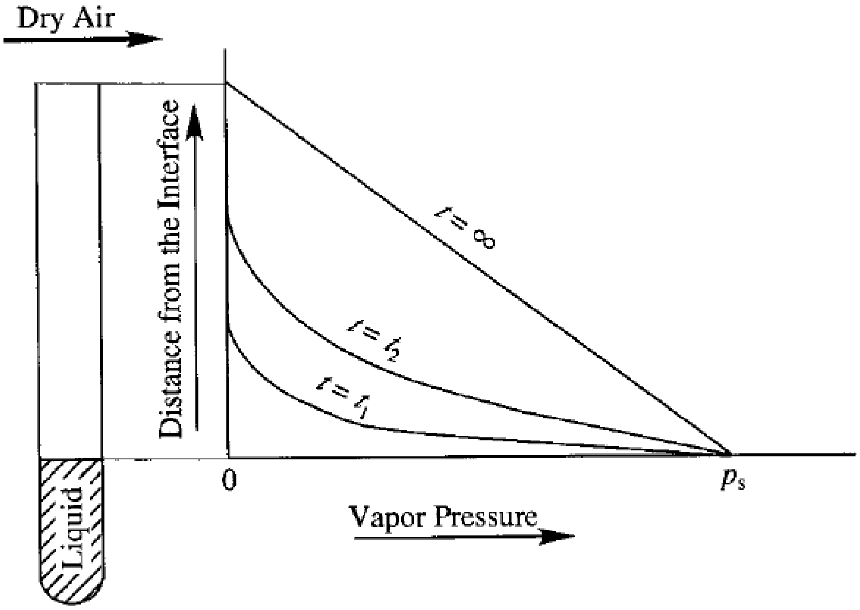


- **Fick’s Law of Diffusion**

$$J_A = -cD\frac{dx_A}{dy}$$

Or

$$J_A = -D\frac{dc_A}{dy}$$



Diffusion of vapor in a gas

Note

- If we place a small amount of a volatile liquid in the bottom of a test tube and let it be in contact with a dry air stream, as shown in the previous Fig., a linear concentration profile is established in the test tube at steady state, and steady evaporation of the liquid will take place.
- This phenomenon, whereby a transfer of material is caused by a non-uniform distribution of concentration, is called *diffusion. The following* empirical law is known for the rate of diffusion:

$$J_A = -cD\frac{dx_A}{dy}$$

- where *c is the molar density [kmol* m^{-3}*], D is the diffusivity [*$\text{m}^2\ \text{s}^{-1}$*],* J_A *is the rate* of diffusion of component ***A per unit area of the surface (diffusional flux)*** [$\text{kmol}_A\ \text{m}^{-2}\ \text{s}^{-1}$], and *y is the distance in the direction of diffusion [m].*
- Previous Equation was first reported by A. Fick in 1855 following observation of the dissolution of salt in water and so is referred to as *Fick’s law of diffusion.*

Phase Equilibrium

- The fact that the upper limit of a mass transfer is restricted by the relevant phase equilibrium and that the rate of mass transfer also depends on the phase equilibrium means that we have to be familiar with the phase equilibrium of the system before we can deal with mass transfer problems. Here, we briefly summarize some of the important quantitative relationships of the phase equilibria commonly encountered in gas-liquid systems.
- For details, see chemical engineering thermodynamics text books.

- ***Solubility of gases in liquids:*** The solubility of a gas in a liquid usually increases with increasing pressure and decreases with increasing temperature. For sparingly soluble gases, the well-known Henry's law applies:

Low concentration

$$p_i = Hx_i$$

where *H is the Henry constant [MPa], p_i is the partial pressure of component i* [MPa], and *x_i is the mole fraction of dissolved gas in the liquid in equilibrium* with the gas.

- ***Vapor pressures of pure liquids:*** The vapor pressure of a pure liquid is a function only of temperature and can be approximated by *Antoine's equation over a wide* range of temperatures:

$$\log p^* = A - \frac{B}{T + C}$$

where *p* is the saturated vapor pressure of the liquid [Pa], T [K] is the temperature,* and *A, B, and C are so-called Antoine's constants.*

- ***Vapor pressures of solutions:*** The vapor pressure of a component *i in a solution* consisting of members of the same chemical series, such as a mixture of homologous paraffin hydrocarbons, is expressed by the following equation:

$$p_i = p_i^* x_i$$

Raoult's law

- Solutions can be classified into two groups, *ideal solutions, which obey Raoult's* law, and *non-ideal solutions, which do not obey Raoult's law*

FINALLY

You will take all the equilibrium correlations in the chemical engineering thermodynamics course [thermodynamics 2]