Mass Transfer

by

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Course

- Diffusion, mass transfer, interphase mass transfer
- Unit operation involves mass transfer
    - Distillation (Gas-liquid contact)
    - Absorption (Gas-liquid contact)
    - Extraction (liquid-liquid contact)
    - Leaching (solid-liquid contact)
    - Drying (Gas-solid contact)
    - Crystallization (solid-liquid contact)
    - Adsorption (solid-liquid/gas contact)
    - Membrane separation (solid- liquid/gas)

Mass Transfer Operation
Course objective

- Fundamental of diffusion, mass transfer coefficient
- Process design (not mechanical design) of different mass transfer equipment/unit operation equipment

- Size, tray/ stage number

Introduction

- Design and engineer the process & equipments
- Select proper raw materials
- Operate the process efficiently, economically and safely
- Achieve high product yield and quality

Unit operations and Unit processes:

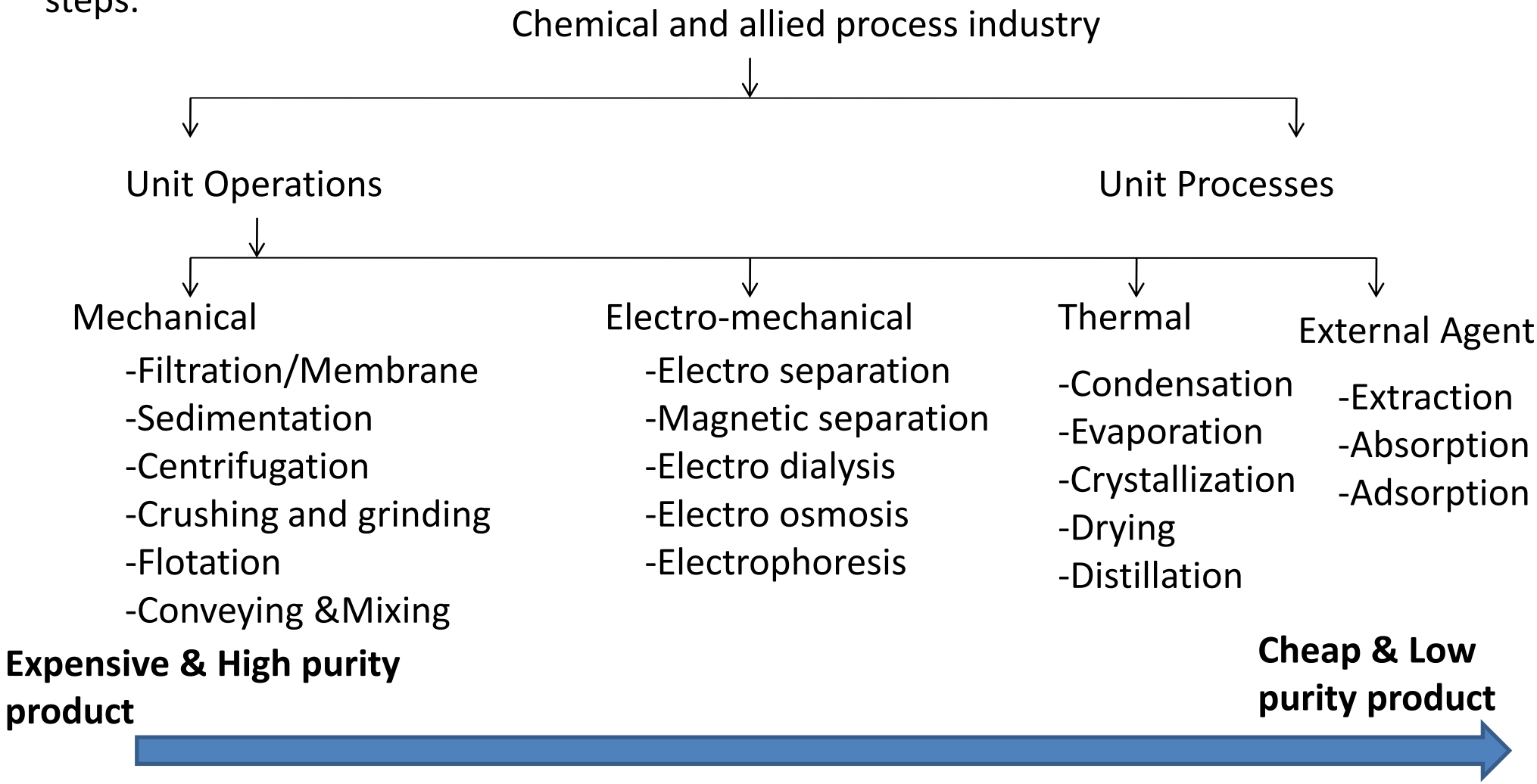
Unit operations – changes are primarily physical

E.g. Common salt manufacture – Evaporation, crystallization, drying and screening

No chemical reaction

Unit processes – Involves both physical and chemical change

E.g. Cracking of petroleum – Catalytic process, distillation and other separation steps.



Mass Transfer

Mass transfer operations?

-Based on principles of mass transfer

-Utilize driving forces to separate a species from a mixture

(e.g., vapor pressure, solubility (or) diffusivity)

Why to study mass-transfer operations?

- Most of chemical process primarily involve purification of raw materials and separation/purification of desired product from by-products.

Separation & Purification cost **α** Final product cost

Initial product conc., C_i → **Separation/ Purification** → Final product conc., C_0

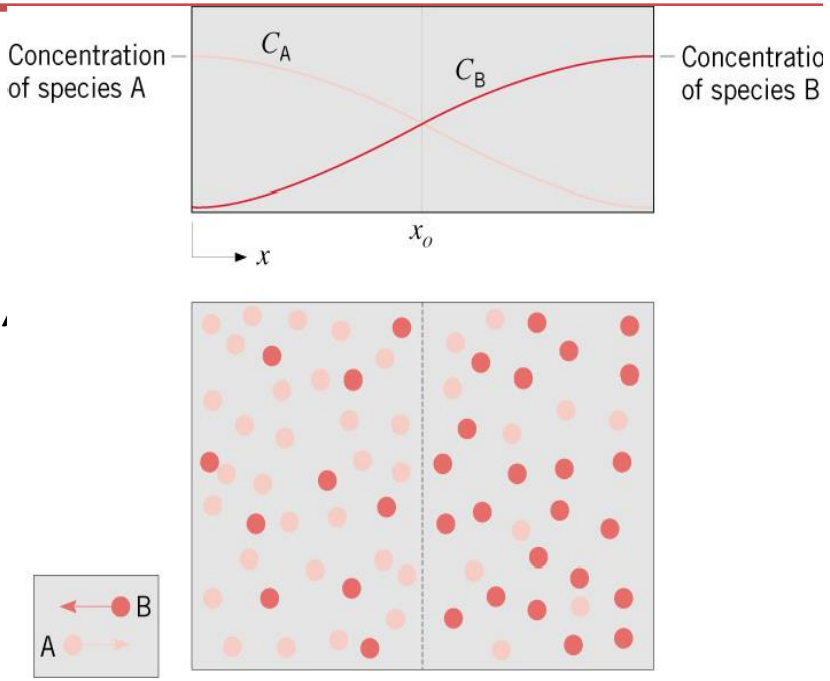
$K = C_0 / C_i$ If K is high, product cost is high

If K is low, product cost is low

Hence, sulfuric acid is cheap as sulfur is available plenty in nature as pure form, but Uranium is expensive as its pure existence in natural form is at low conc.

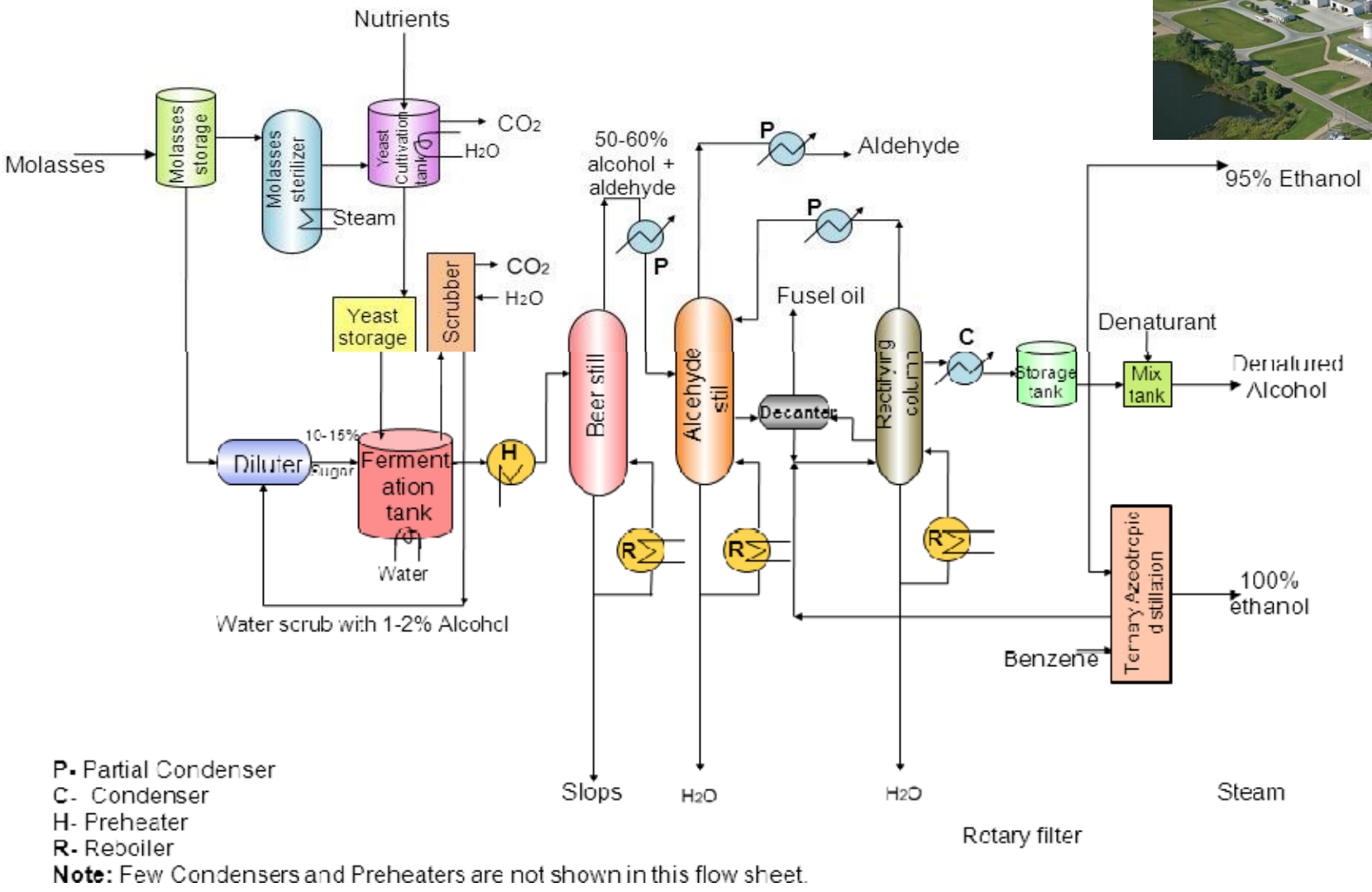
What is mass transfer?

➢The subject of Mass Transfer studies the relative motion of some chemical/biochem species, Driven by concentration gradients

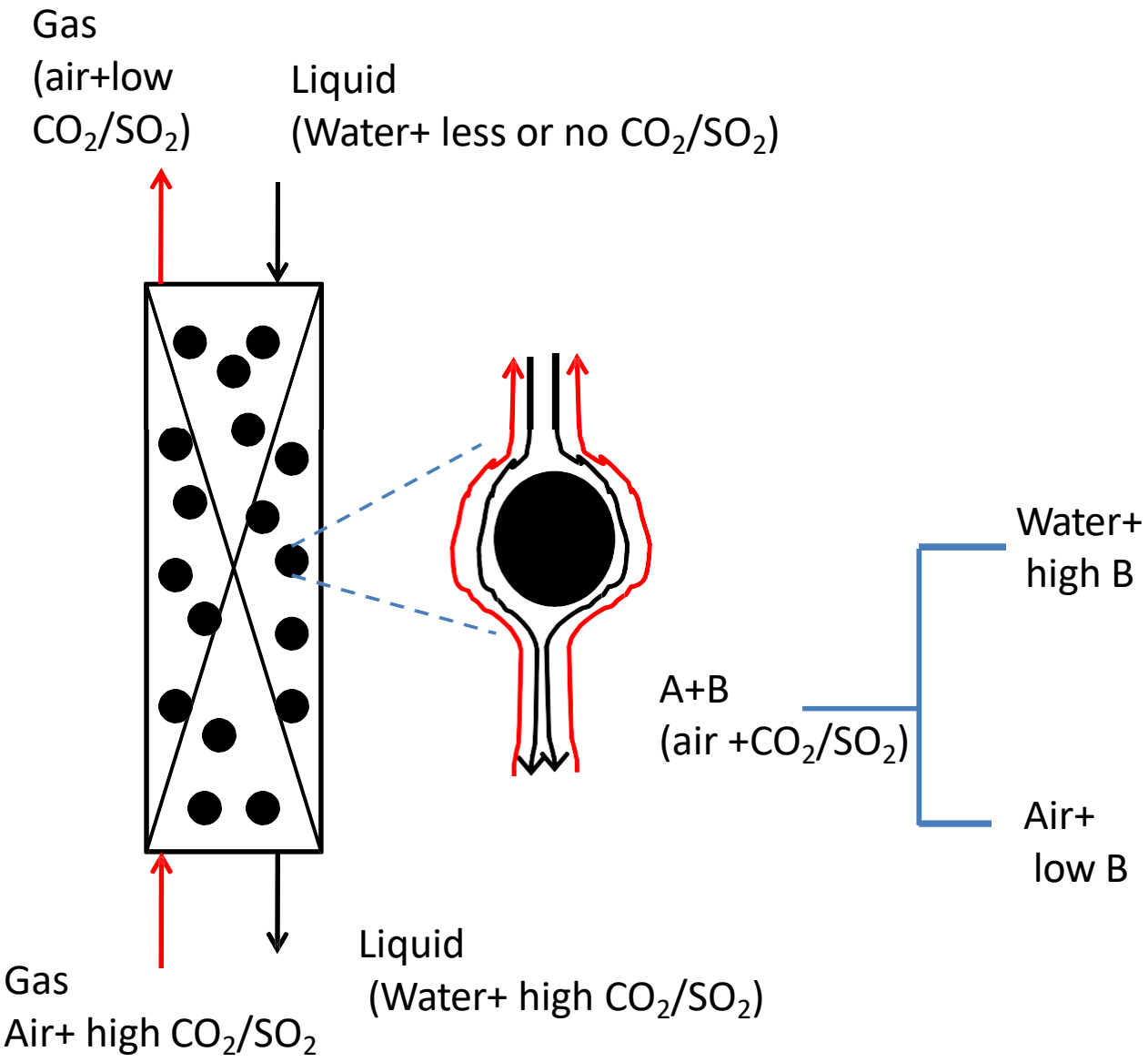


- Basis for many chemical and biological processes such as the removal of sulfur dioxide from the flue gas, a chemical process, separation of alcohol, a bioprocess, or the design of an artificial kidney, a biological process.

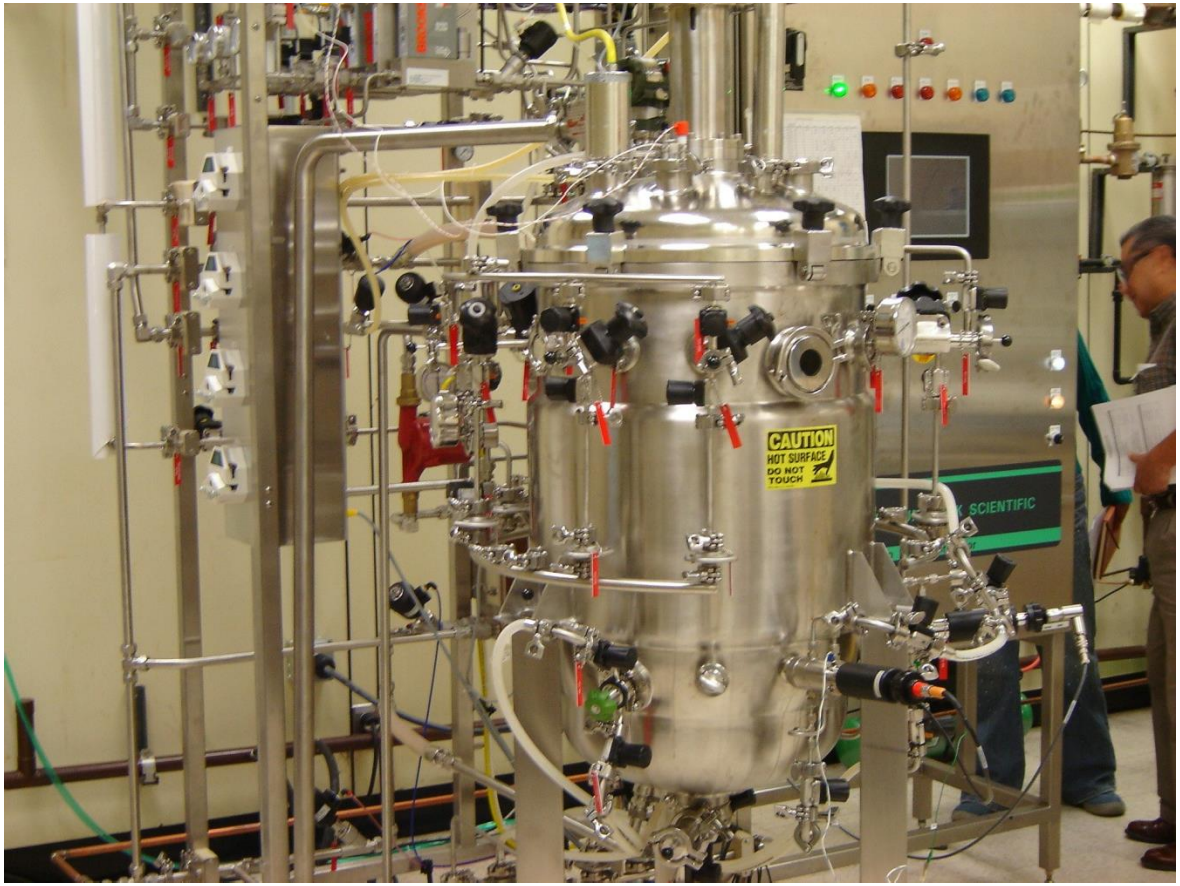
Ethanol bioprocess

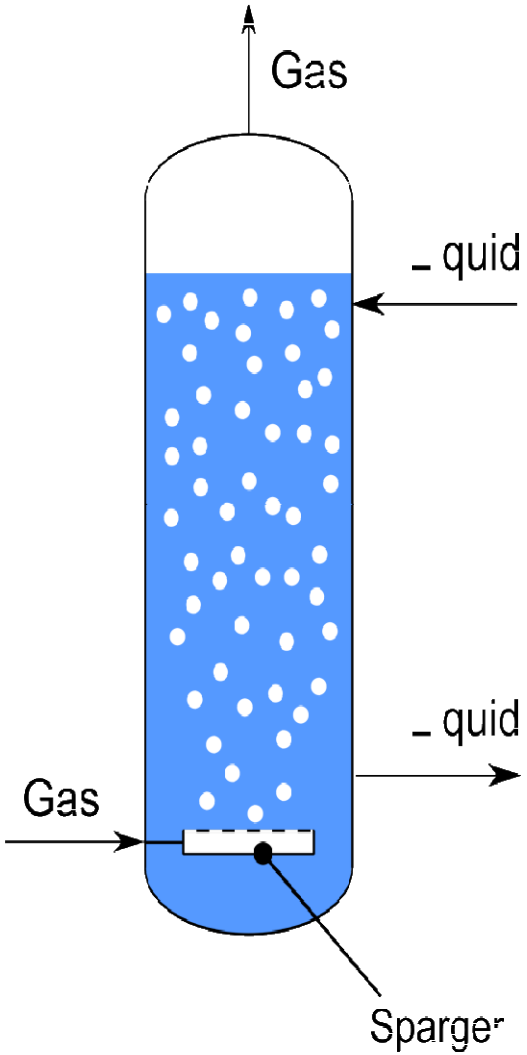


Absorption


Gas
(air+low
CO_2/SO_2)
Liquid
(Water+ less or no CO_2/SO_2)
Water+
high B
A+B
(air +CO_2/SO_2)
Air+
low B
Liquid
(Water+ high CO_2/SO_2)
Gas
Air+ high CO_2/SO_2

Gas (air) Bubble mass transfer to fermentation culture





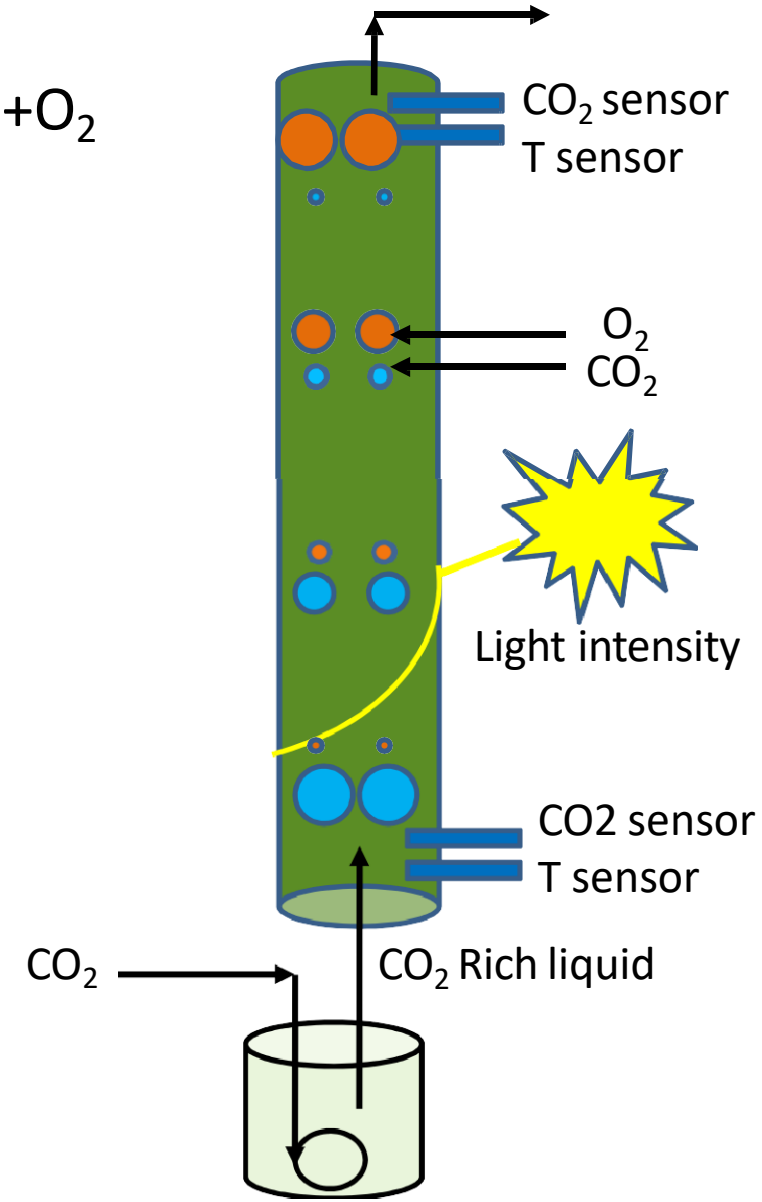
N, P, Fe, Photon

$CO_2 + H_2O$ → (Sugar, protein, lipid) $+O_2$

- CO_2 limiting regime:
  Depends on : algal density,
  flow rate,
  sunlight intensity

- Diameter of the reactor:
  Depends on Optical path length
  algal density
  sunlight intensity)

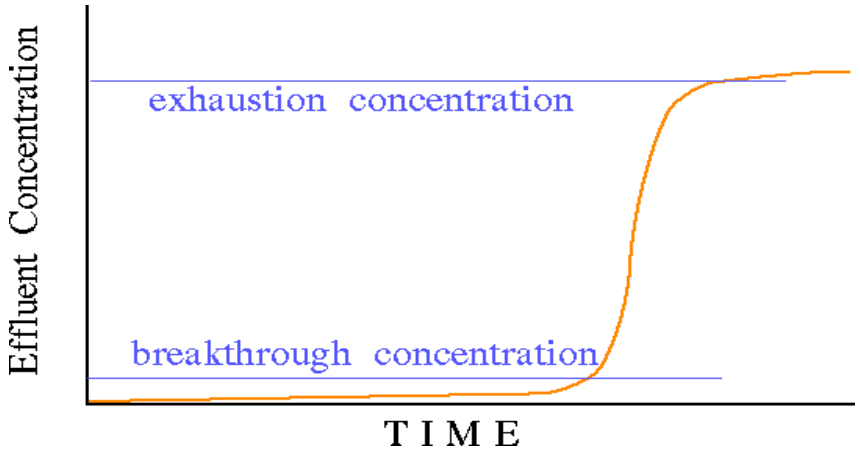
- O_2 inhibition on growth: use for height

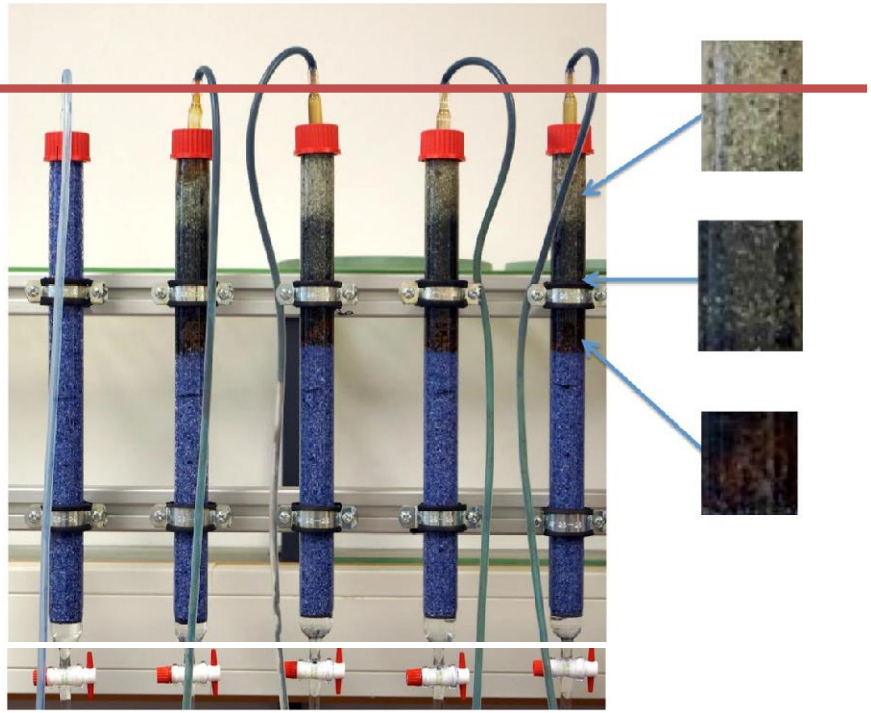


Absorption/desorption

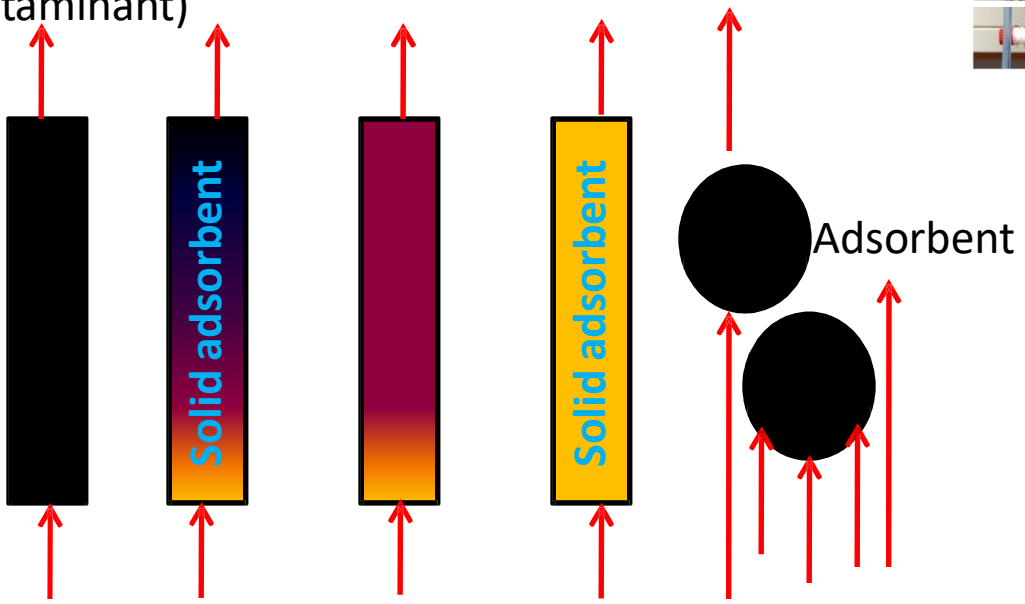
- absorption of gas (volatile component) from a gas mixture (e.g. CO2-air, SO2-air) into a liquid solvent in packed columns.
- In air pollution control, the various oxides of nitrogen can be removed by absorption with water, sulfuric acid, and organic solutions. Gaseous ammonia can be removed by absorption with water.
- Purification of gas stream
- Food industry/ chemical industry/biotech industry

Adsorption/desorption





(water +low contaminant)

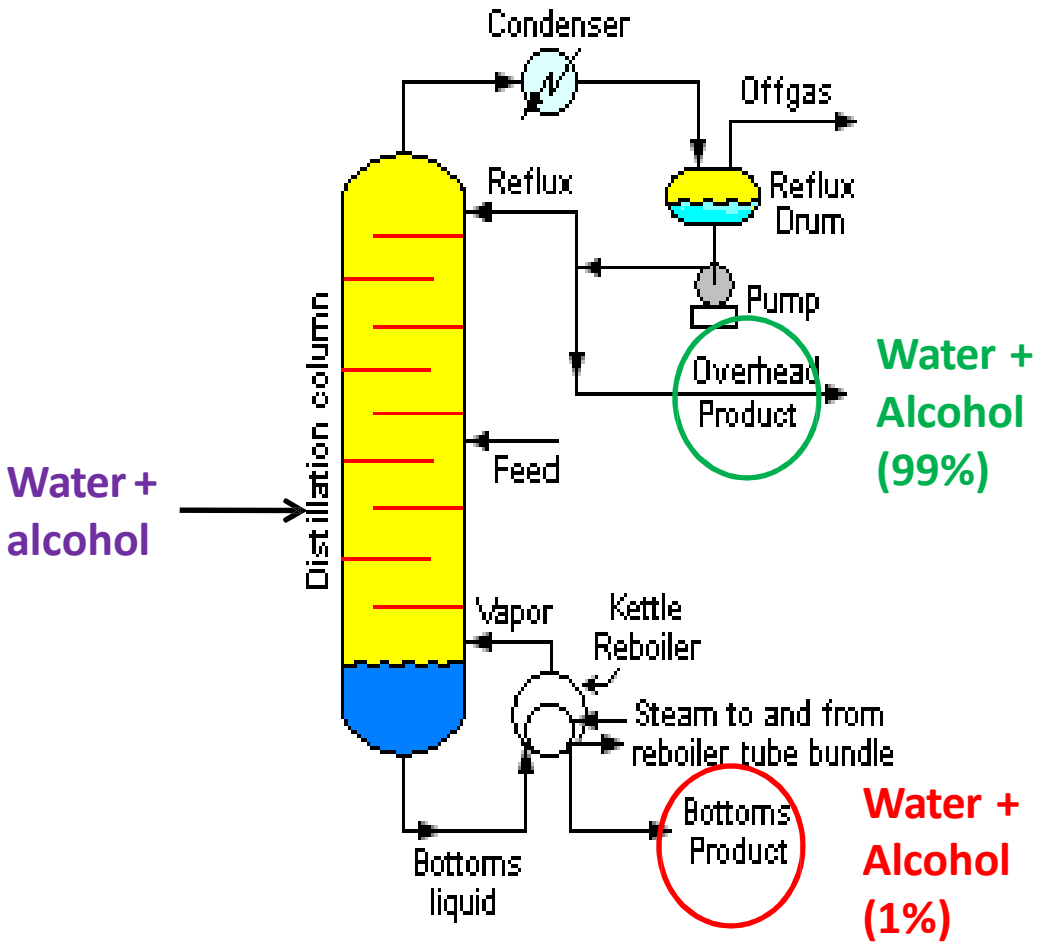


Waste water (water +contaminant)

Waste water (water + contaminant)

- Water+ low contaminant
- Solid matrix (biomass /others)with high contaminants

Separation and purification of feed & product: distillation



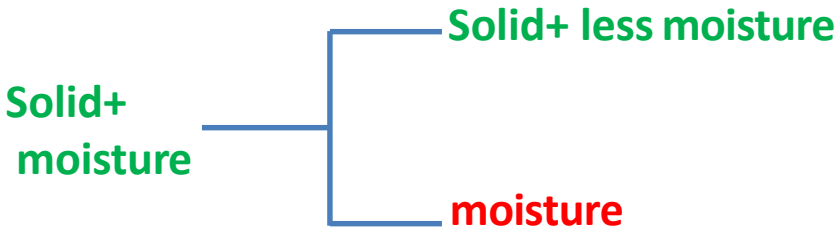
Water + B

water+ high B

water+ low B

Drying

- Used in many process industry
- Sugar industry , food industry, pharmaceutical industry, paper industry
- Natural air drying, supercritical drying (used superheated steam), freeze drying

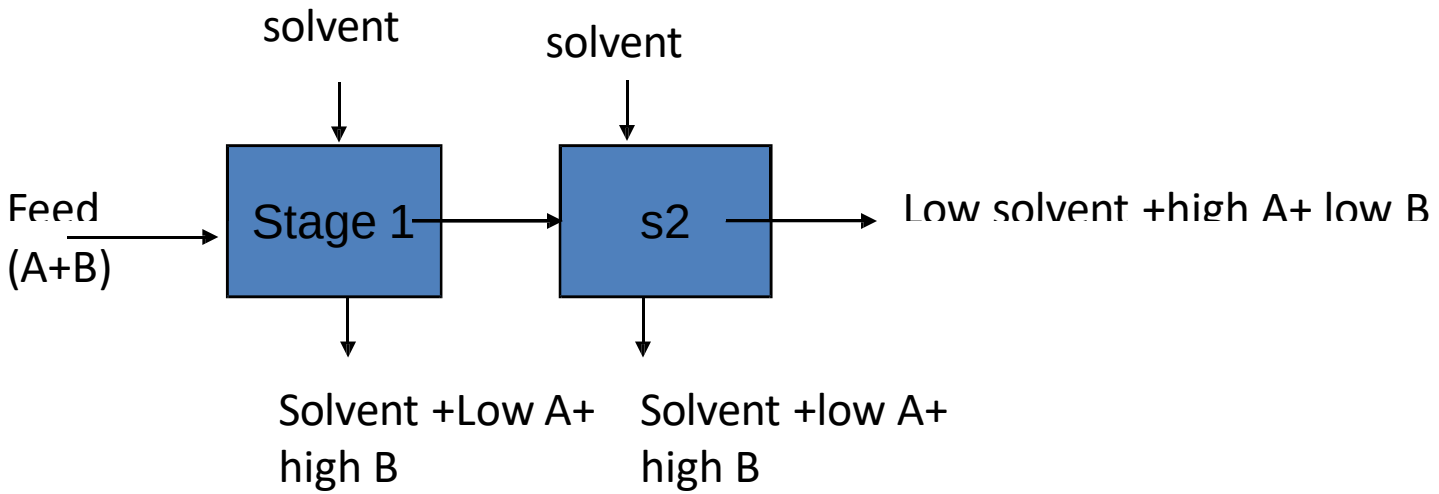


Extraction (solvent)

➢ ***Extraction of penicillin from fermentation broth using organic solve butyl acetate***

Temperature sensitive product

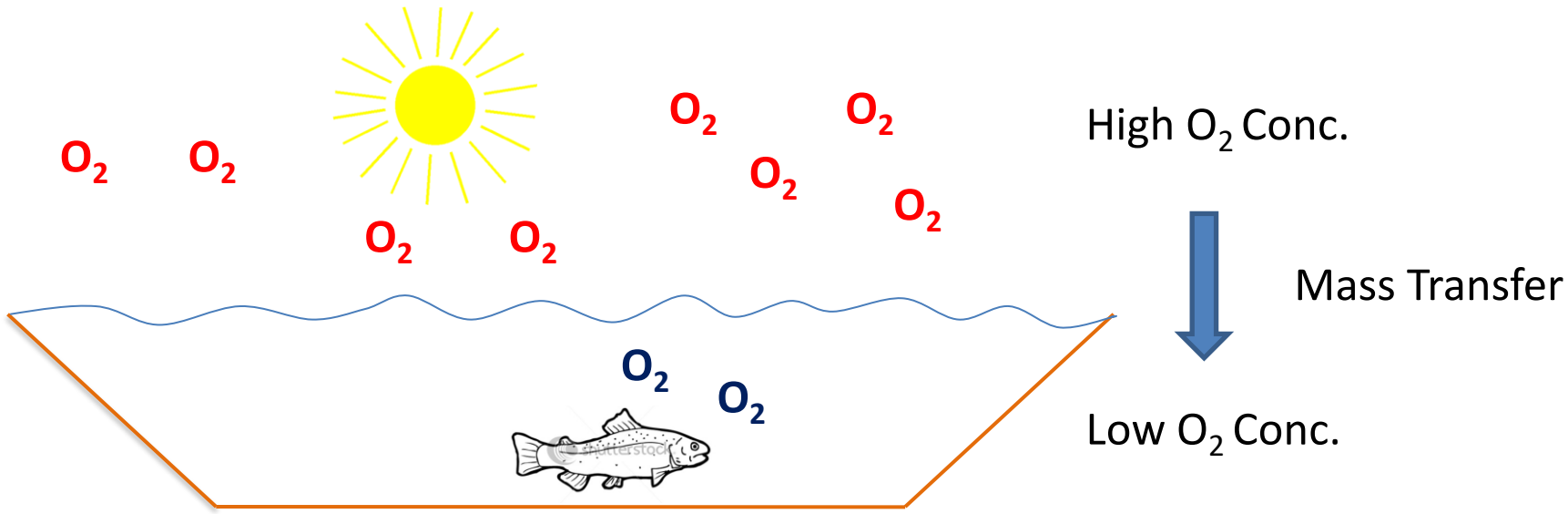
Two immiscible liquid



What is Mass Transfer?

Transport of a species from one point to another generally **in the presence of a difference in concentration (or partial pressure), called the 'driving force'.**

However, mechanical shifting of a mass (or) body is not a mass transfer operation as it is not caused by a concentration driving force – Filtration, Centrifugation processes are known as mechanical separation processes.



Driving force = Concentration difference

Larger the departure from equilibrium conc., high the driving force and rate of transport

Moisture removal:

H_2O

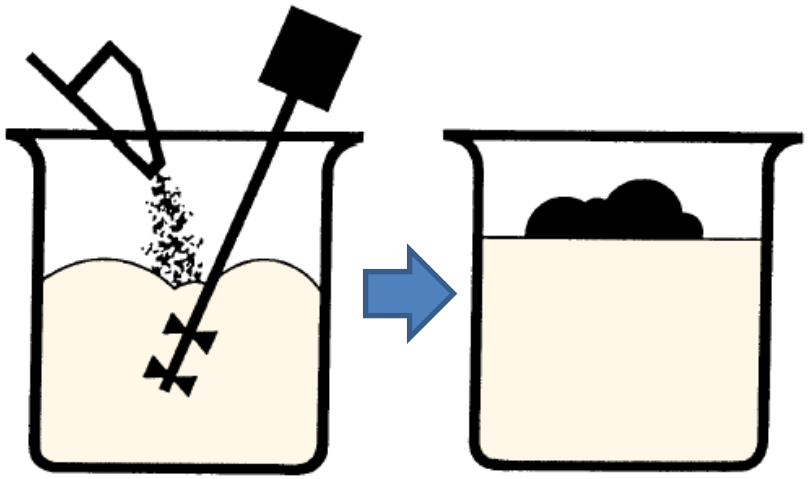
Drying

Vapor pressure of moisture in food material

> Partial pressure of moisture in surrounding air

Driving force = Vapor pressure

Solubility of Sugar :



Supersaturated solution rejects solute as crystals

Driving force = Solubility

Types of Mass Transfer

Diffusional

- random movement through molecular motions of individual molecules
- Absence of Macroscopic medium (e.g. migration of moisture within food material, transport of reactant or product in a catalyst pellet)

Convective

-Mass transfer occurs in a fluid medium

-Rate of mass transfer is high (turbulent & mixing)

(e.g. removal moisture by surrounding air)

Major three modes of transport in chemical engineering

Heat

Driving force: Temperature gradient

Mass

Driving force: Concentration gradient

Momentum

Driving force: Velocity gradient

Heat transfer is more analogous with mass transfer – similar approach for analysis of problems

However some significant difference exists…..

Heat Transfer	Mass Transfer
Mostly occur by indirect contact of phases (e.g. heat exchanger) Thermal equilibrium of two phases stands for same temperature Driving force is always expressed as temperature gradient	Occur by direct contact of miscible (or) immiscible phases (e.g. extraction) Two phase equilibrium doesn't need to be in same concentration – Thermodynamic equilibrium Driving force can be represented in different ways e.g., concentration, partial pressure and solubility gradients

Mass-Transfer Operations

Direct contact of two immiscible phases:

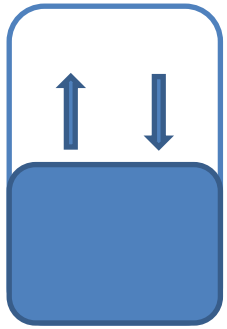
Pure system – one of the phases at equilibrium contains only one component

E.g. Aqueous salt solution – water vapor

Separation possible by either boiling water from solution (or) freezing out salt and water crystals. Two phases formed are in final equilibrium and is not a time-dependent process.

Not a typical mass-transfer operation!

In mass transfer operations –**neither equilibrium phase contains a single component** and when two phases are contacted **they will not be of equilibrium compositions.** The system **attempts to reach equilibrium by a relatively slow diffusional movement**.



Therefore separations are never complete, but brought to near completion by appropriate manipulations!

Classification of Mass-Transfer Operations

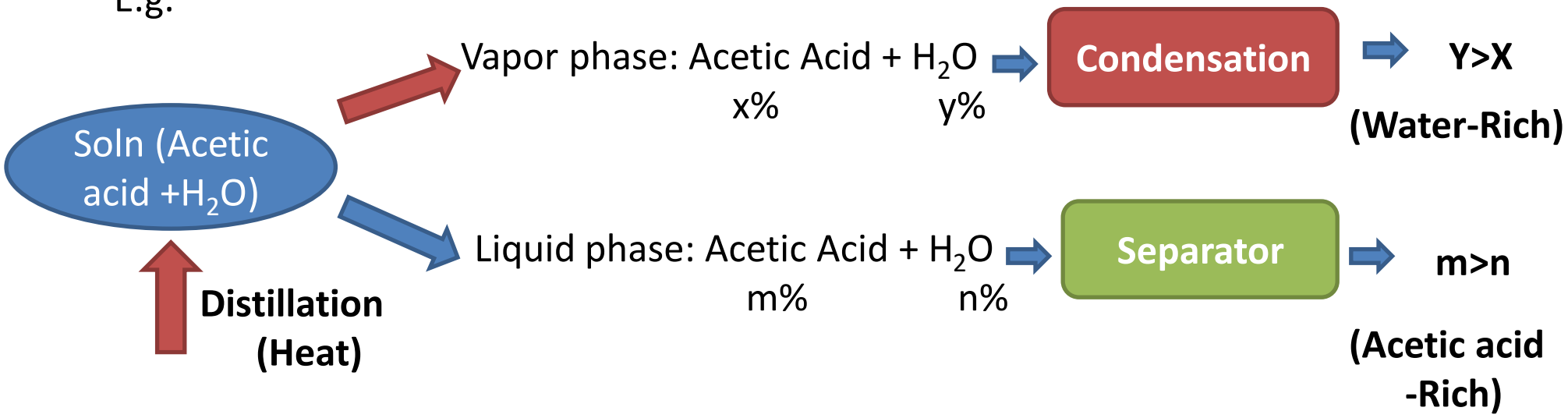
Classified in to three states of aggregation (gas, liquid and solid) with six possible phase Contacts:

1. **Gas-Gas:** Most of gases are completely soluble each other and is not practically realized.
2. **Gas-Liquid:**

   (a) Fractional distillation:

   If ALL the components distribute between the phases at equilibrium, the operation is known as fractional distillation (or) distillation.

   E.g.



2.(b) **Absorption**: **If both phases are solutions and one common component** (or group of components distribute between phases).

E.g. **NH_3 + Air** (H_2O) → **Air** (100 % y)

(X) (Y) → **NH_4OH** (100 % x)

Desorption (or) stripping – air in contact with ammonia-water solution

(c) **Humidification/Dehumidification of air:**

If the liquid phase is a pure liquid containing one component, **but gas contains two or more components**

Water (liq) $\xrightarrow[\text{Evaporation}]{\text{Dry air}}$ Humidified air

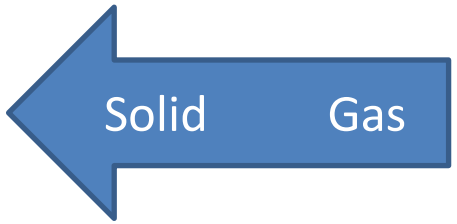
Water (liq) $\xrightarrow[\text{Condensation}]{\text{Wet air}}$ Dehumidification

3. Gas-Solid: If solid solution is partially vaporized without appearance of liquid phase, the **newly formed vapor and solid phase contains all original components in different proportions** (**Fractional Sublimation**) **(theoretically possible but practically doesn't)**

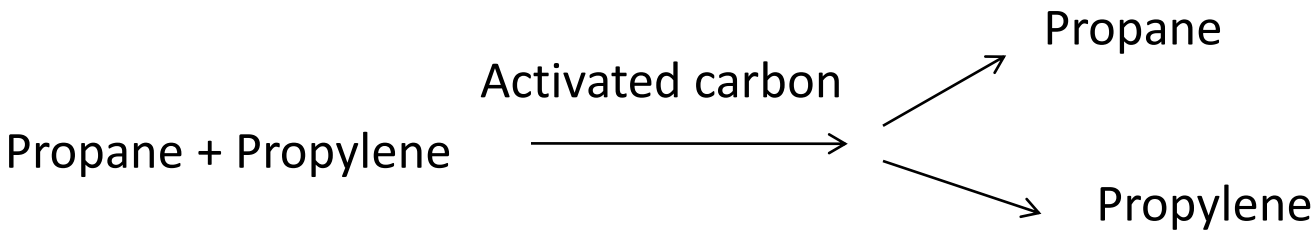
E.g. Moist solid $\xrightarrow{\text{Dry gas}}$ H_2O + gas (Drying or desorption)

Classical e.g. drying clothes

Moist Air $\xrightarrow{\text{Act. Silica gel}}$ Dry air (Adsorption)

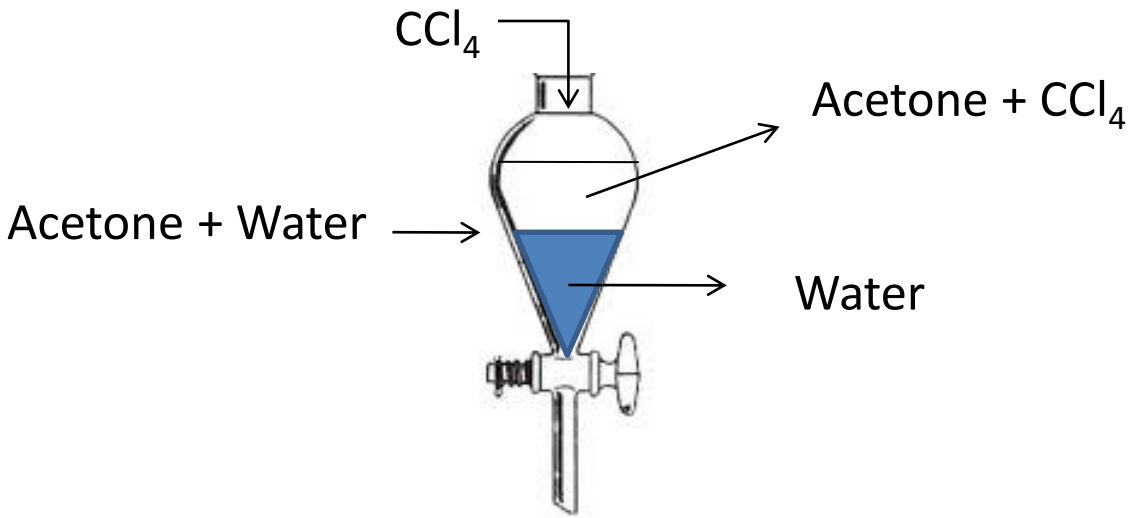


Fractional Adsorption: Differential adsorption of components of a gas mixture on a solid adsorbent



Rate of heat transfer > Rate of diffusion **E.g. condensation of vapor & drying moist solid**

4. Liquid-Liquid: Separations involving contact of **two insoluble** liquid phases (liquid-extraction)



5. Liquid-solid: **When constituents are present in both phases at equilibrium**, separation of soluble constituent achieved by **Fractional crystallization** (for liquid mixture) and **Leaching** (in case of solid)

Crystallization :

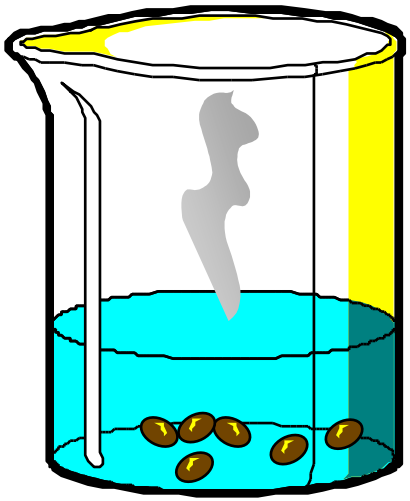
Conc. sugar solution
(in sugar industry)

Crystallizer

Mother liquor

Sugar crystals

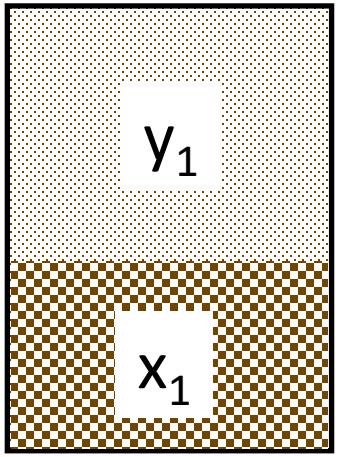
Leaching: Coffee extraction



coffee

$y_1 = K x_1$

beans

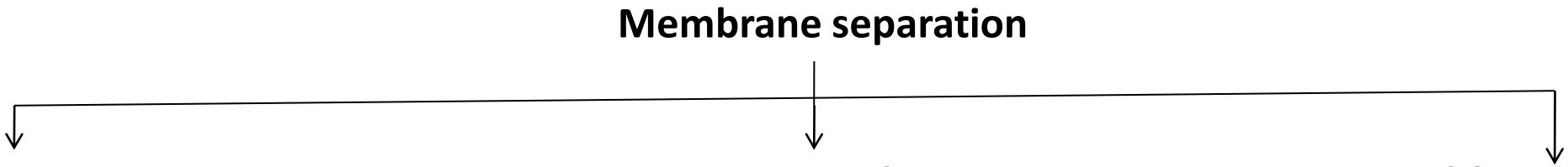


6. Solid-Solid: Due to extraordinarily slow mass transfer rates, not preferred for practical use

Membrane separation:

Membrane acts as barrier and permits movement of species by diffusion

Wide industrial application !



Gas-gas

Micro porous membranes

- Gas separation by difference in diffusion rates based on MW

Permeation

-Gas separation by diff. in solubility

-Membranes are not porous and gas first dissolves in membrane & diffuse later

(e.g. Helium from natural gas by fluorocarbon membranes)

Gas-Liquid

- Permeation

(e.g. Liquid soln of alcohol & H_2O, alcohol permeates in to non-porous membrane)

Liquid-liquid

E.g. Dialysis

(Beet-Sugar soln)

Electrodialysis

Reverse Osmosis