Lecture 2.
Basic Separation Concepts (1)
[Ch. 1]

- General Separation Techniques
  - Separation by phase creation
  - Separation by phase addition
  - Separation by barrier
  - Separation by solid agent
  - Separation by external field or gradient

General Separation Techniques

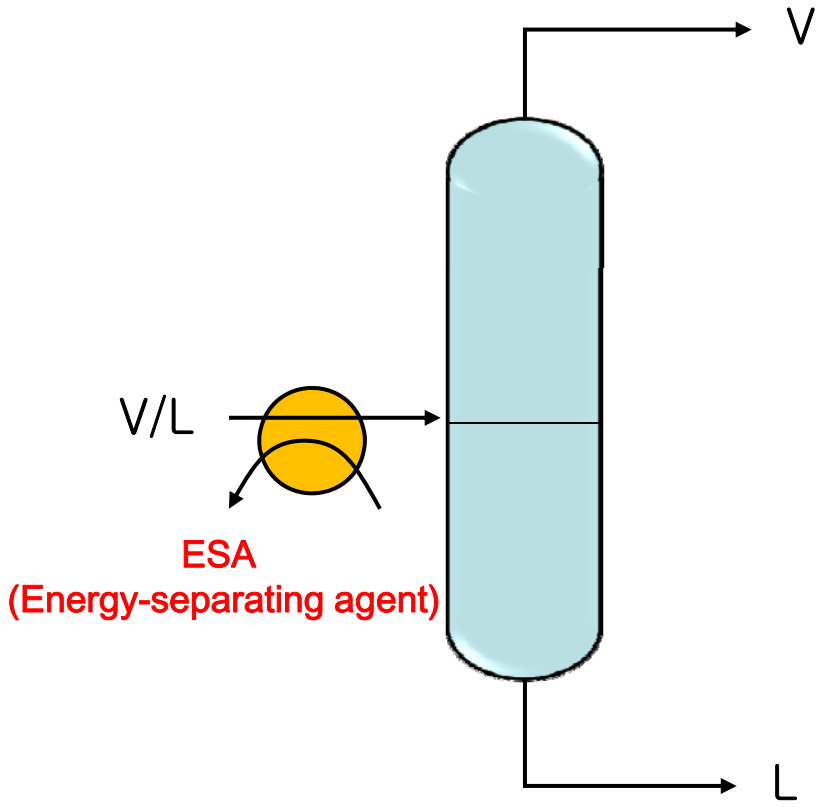
- Separation by phase creation
  - Create a second phase that is immiscible with the feed phase
  - Distillation, crystallization
- Separation by phase addition
  - Introduce a second phase in the form of a solvent
  - Solvent extraction
- Separation by barrier
  - Restrict and/or enhance the movement of certain chemical species
  - Membrane separation
- Separation by solid agent
  - Add solid particles that act directly or as inert carriers for separation
  - Adsorption
- Separation by force field or gradient
  - Apply external fields of various types
  - Centrifugation

Separation by Phase Addition or Creation

- Energy-separating agent (ESA)
  - Heat transfer (heating, cooling)
  - Shaft work can be involved together
- Mass-separating agent (MSA)
  - May be partially immiscible with one or more of species
  - May be completely miscible with a liquid mixture
- Disadvantages of MSA
  - Need for an additional separator to recover the MSA for recycle
  - Need for MSA makeup
  - Possible contamination of the product with the MSA
  - More difficult design procedures

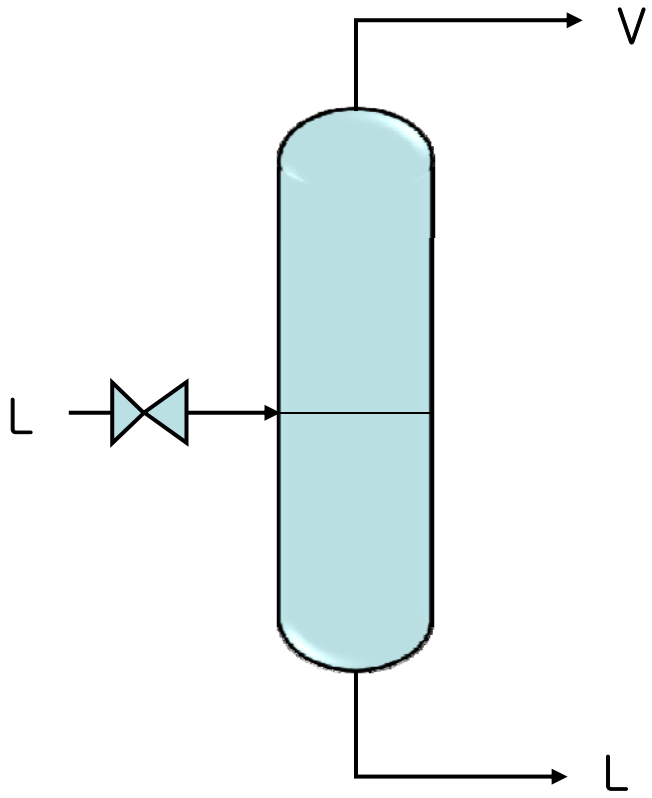
Separation by Phase Addition or Creation

- Partial condensation / Partial vaporization
  (Heat transfer)



Recovery of heavy hydrocarbon components from gas mixtures

- Flash vaporization
  (Pressure reduction)

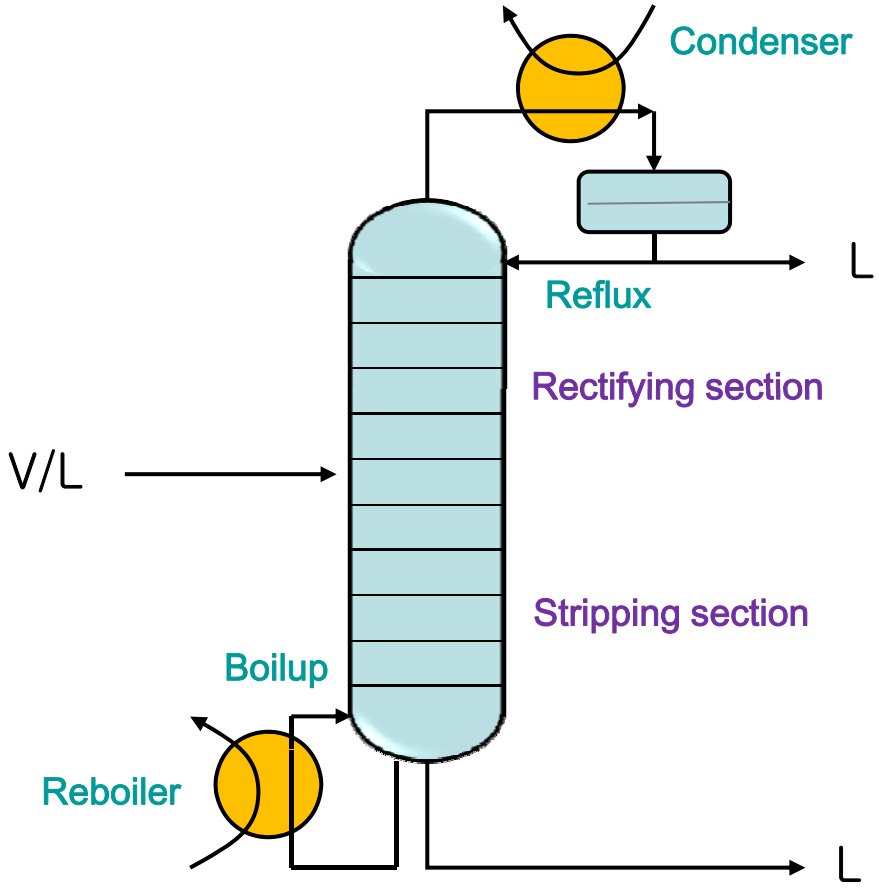


Recovery of water from sea water

Separation by Phase Addition or Creation

- Distillation

(Heat transfer or sometimes work transfer)

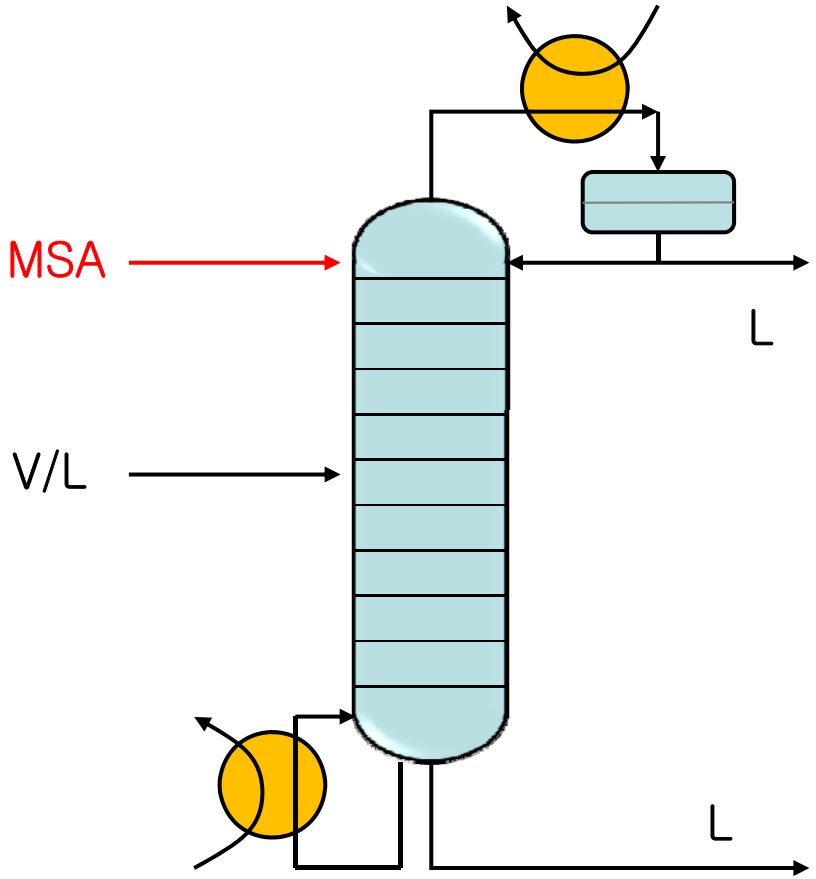


- When the volatility difference among species are not sufficiently large
- Most widely used industrial separation technique
- Multiple contact between counter current flow of V/L in trays (stages)

Separation by Phase Addition or Creation

• Extractive distillation

Liquid solvent (MSA) and Heat transfer (ESA)

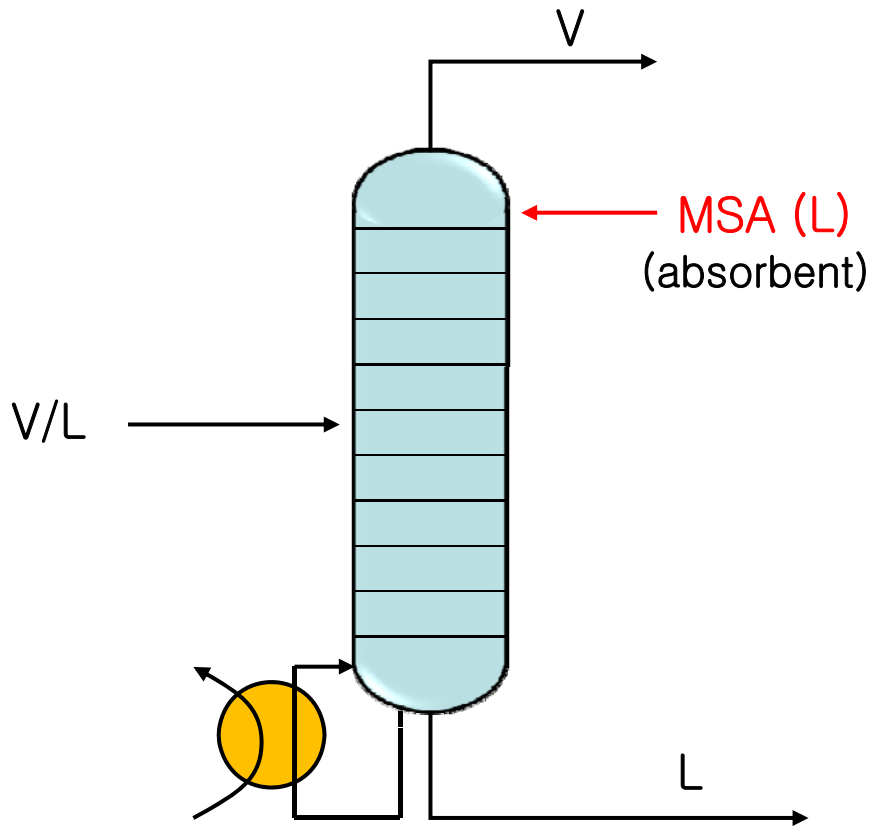


- When the volatility difference among species are so small (more than 100 trays are required)
- MSA is used to increase volatility difference (reducing the number of trays)
- Minimize MSA loss (recycling)
- Separation of acetone (b.p. 56.5℃) and ethanol (b.p. 78.4℃)

Separation by Phase Addition or Creation

- Reboiled absorption

Liquid absorbent (MSA) and Heat transfer (ESA)

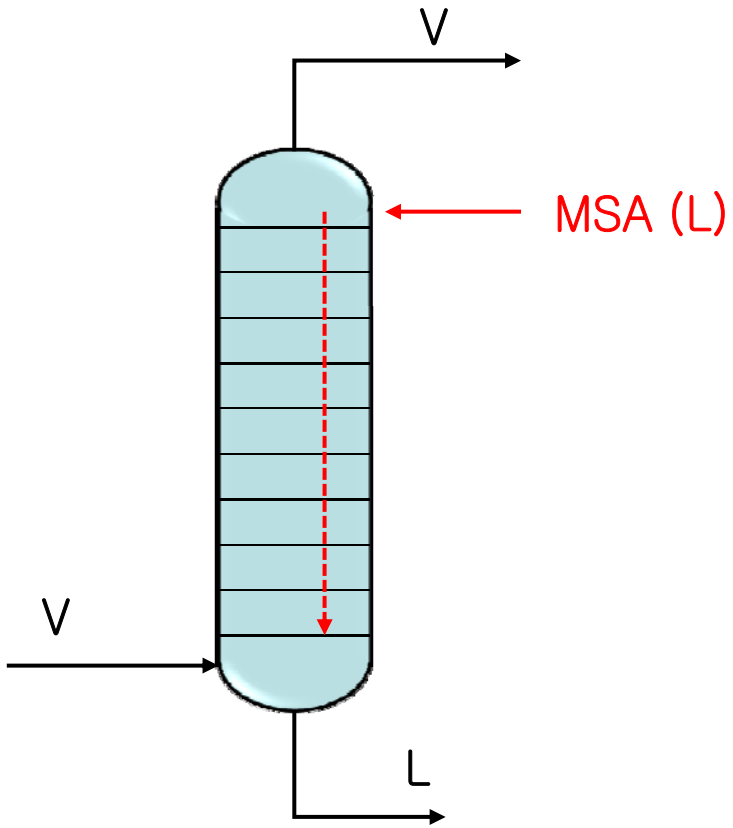


- When condensation of vapor is not easily accomplished
- Removal of ethane and lower molecular hydrocarbons from LPG

Separation by Phase Addition or Creation

- Absorption

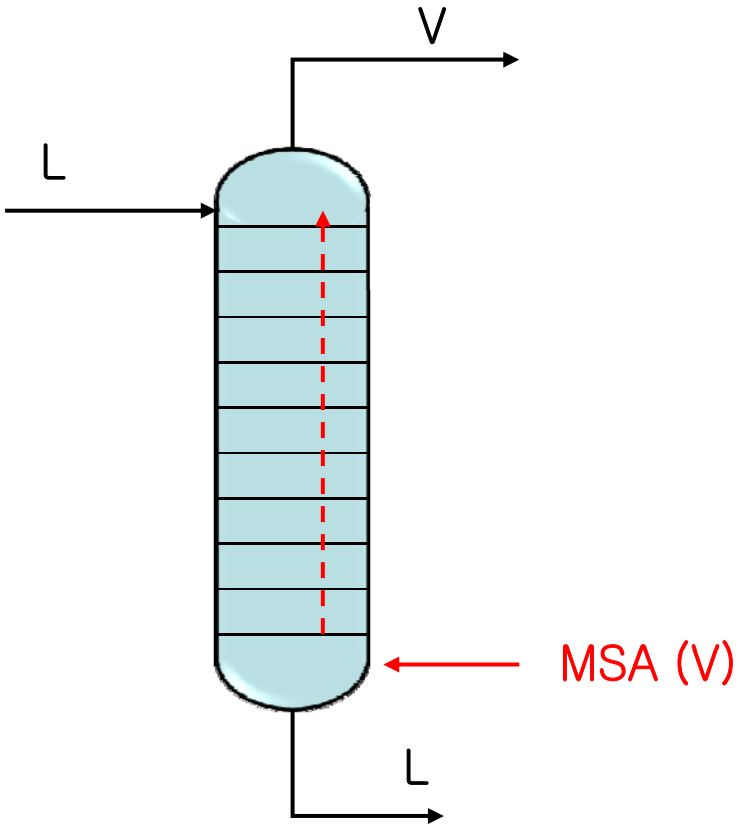
Liquid absorbent (MSA)



Separation of CO_2 from combustion product using ethanolamine

- Stripping

Stripping vapor (MSA)

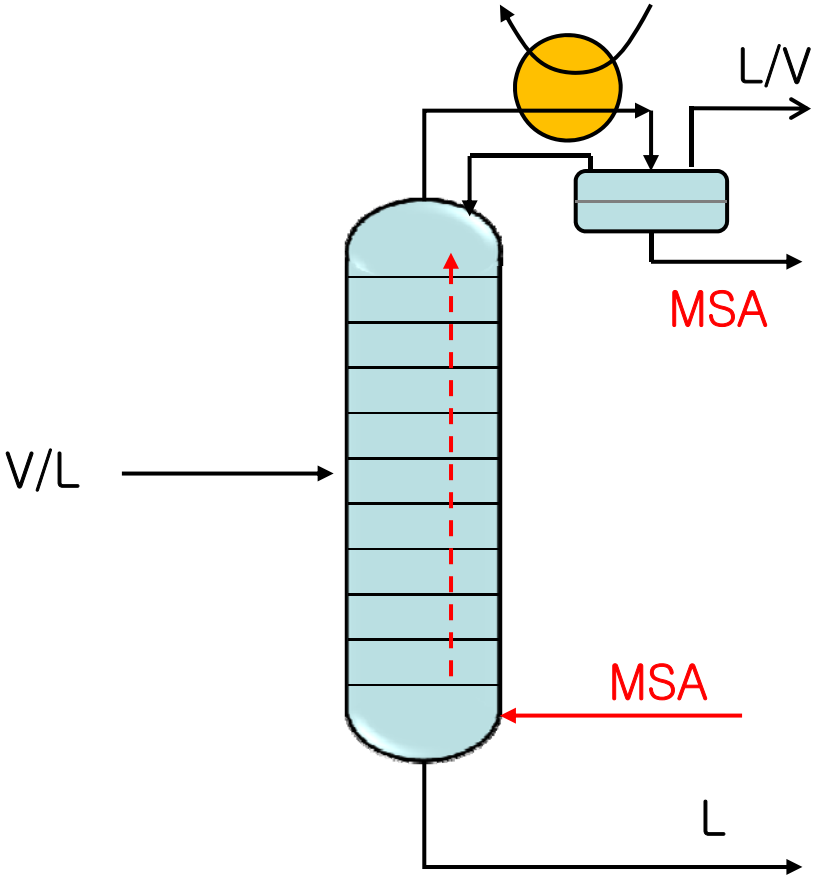


Removal of light ends from naphtha, kerosene, and gas oil

Separation by Phase Addition or Creation

- Refluxed stripping (Steam distillation)

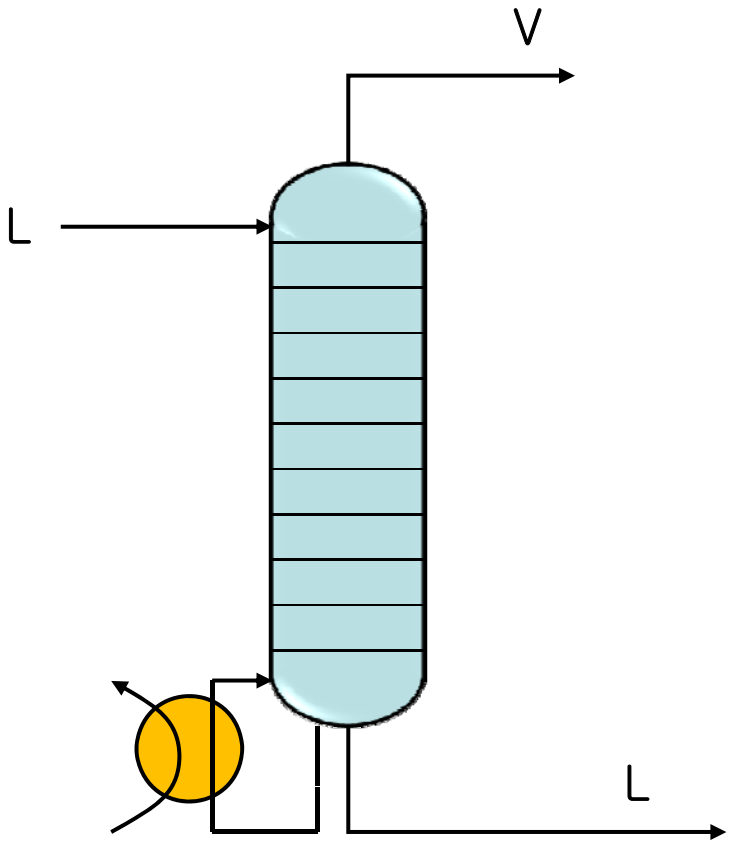
Stripping vapor (MSA)
and Heat transfer (ESA)



Separation of products from delayed coking

- Reboiled stripping

Heat transfer

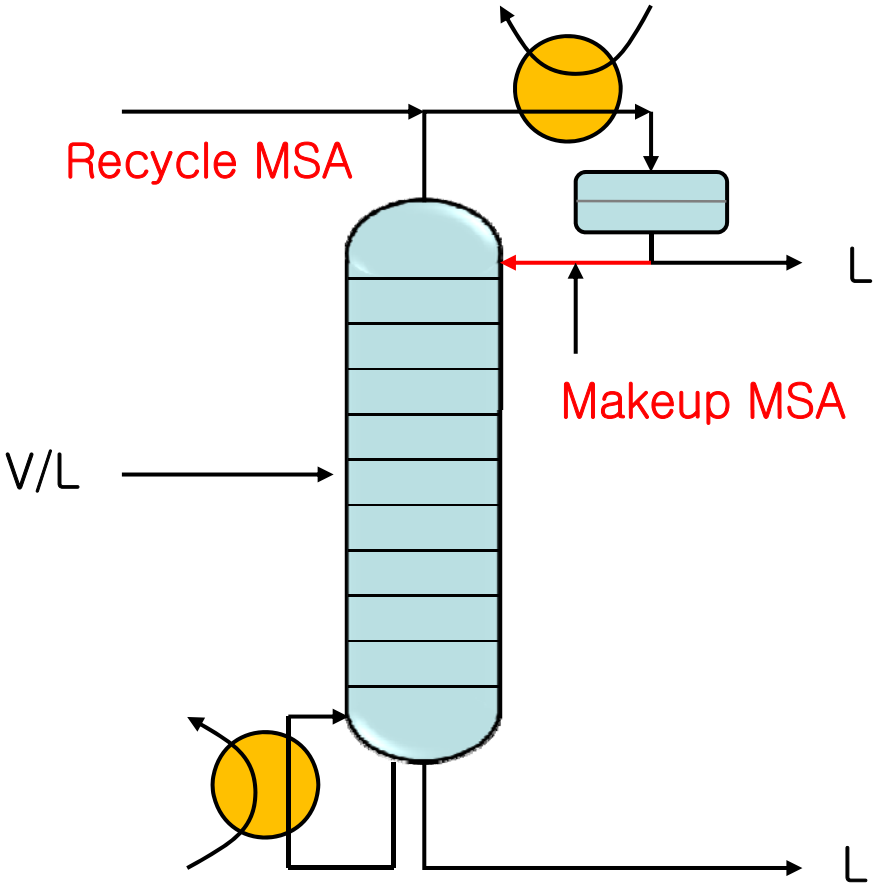


Recovery of amine absorbent

Separation by Phase Addition or Creation

- Azeotropic distillation

Liquid entrainer (MSA) and Heat transfer (ESA)

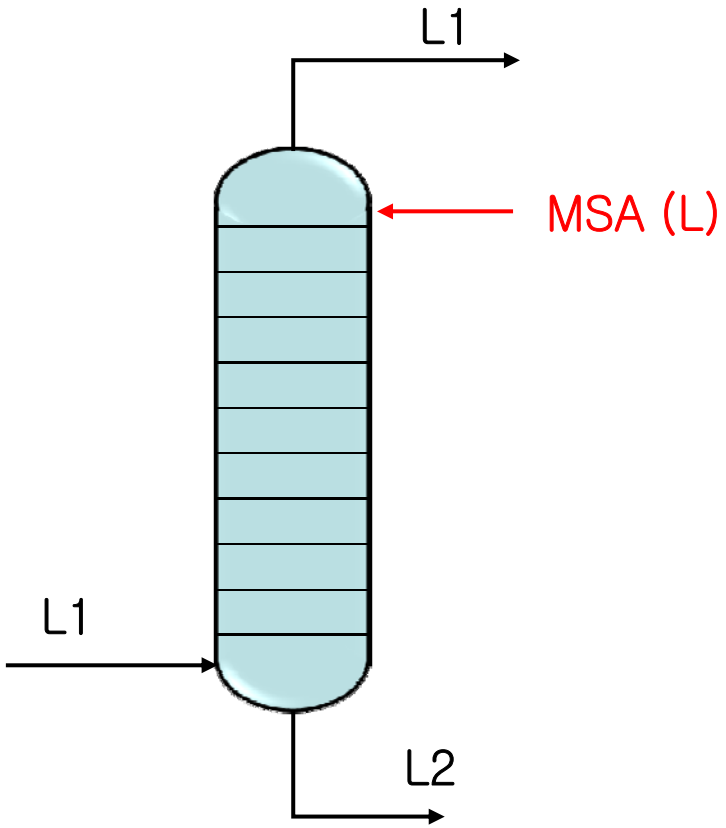


- When minimum-boiling azeotropes are formed
- Recovery of acetic acid from water using n-butyl acetate as an entrainer to form an azeotrope with water

Separation by Phase Addition or Creation

- Liquid – liquid extraction

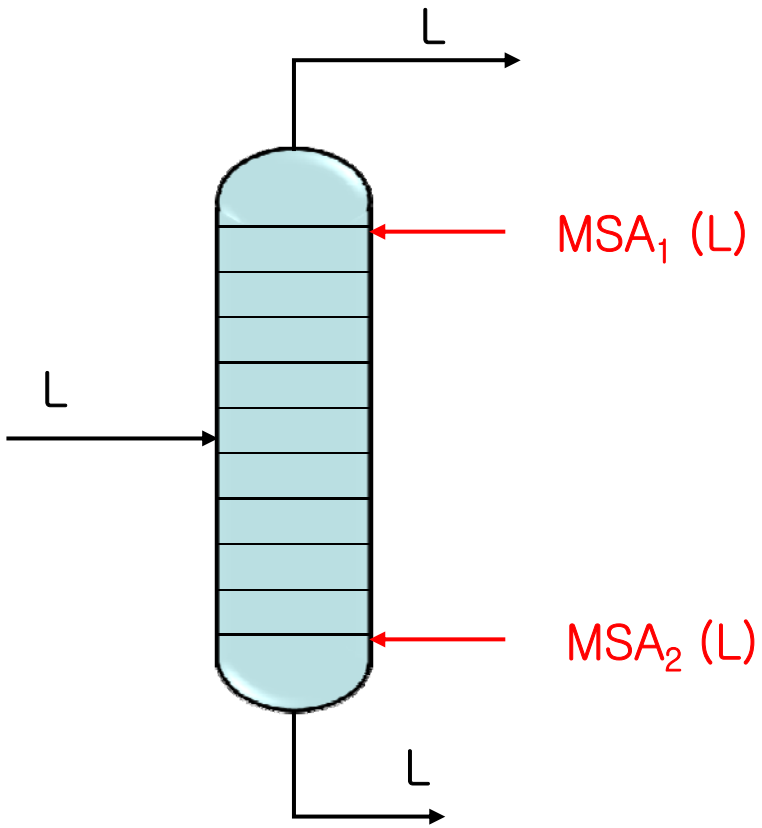
Liquid solvent (MSA)



Recovery of aromatics

- Liquid-liquid extraction (two-solvent)

Liquid solvents (MSA_1 & MSA_2)

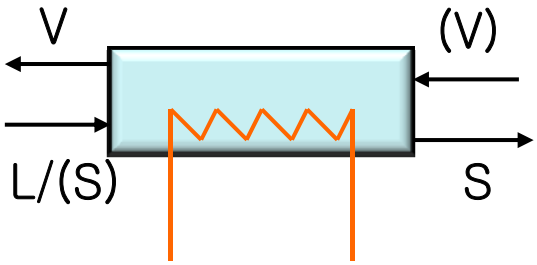


Use of propane and cresylic acid as solvents to separate paraffins from aromatics and naphthenes

Separation by Phase Addition or Creation

- Drying

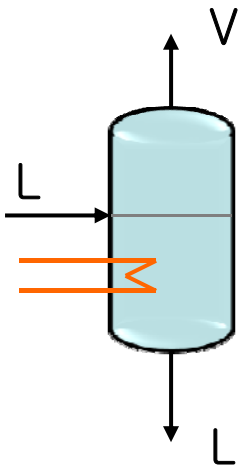
Heat transfer (ESA)



Removal of water from PVC

- Evaporation

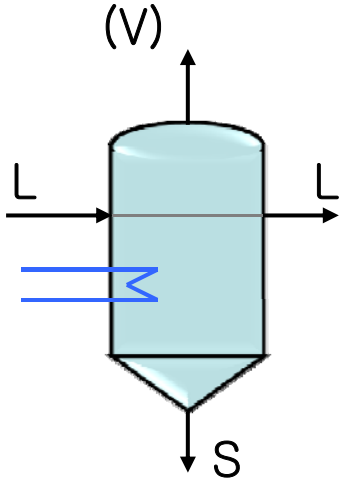
Heat transfer (ESA)



Evaporation of water from water + urea

- Crystallization

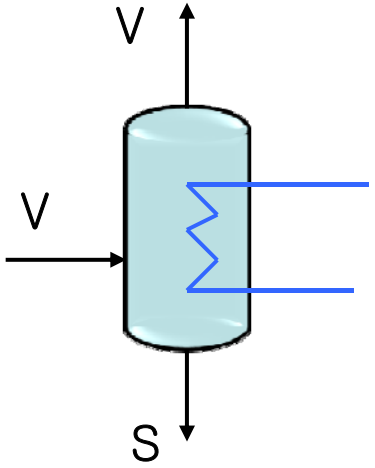
Heat transfer (ESA)



Crystallization of high purity silicon for semiconductor

- Desublimation

Heat transfer (ESA)

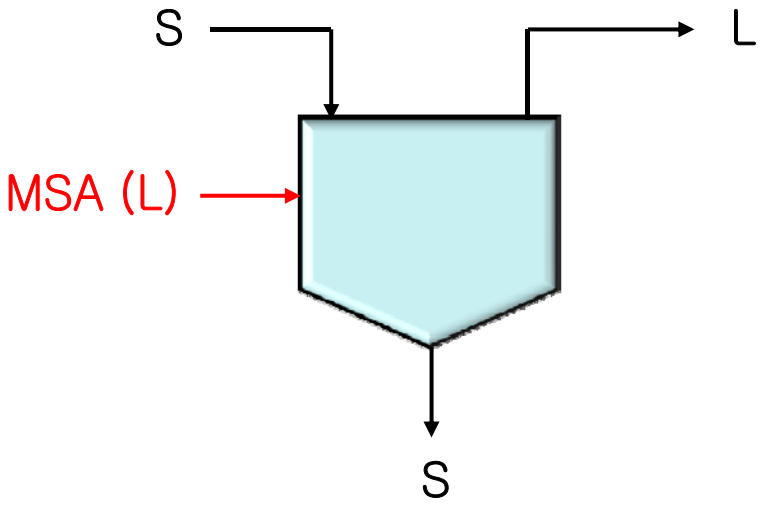


Recovery of phthalic anhydride from non-condensible gas

Separation by Phase Addition or Creation

- Leaching (Liquid-solid extraction)

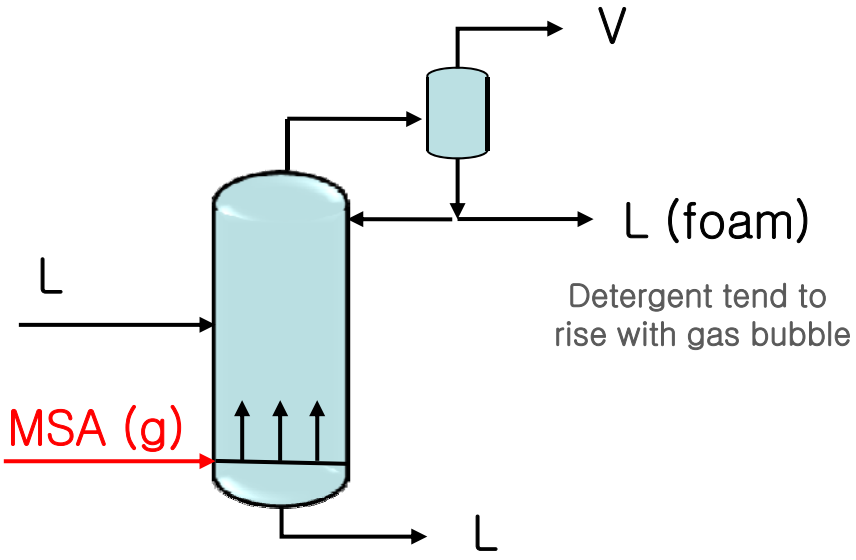
Liquid solvent



Extraction of sugar using hot water

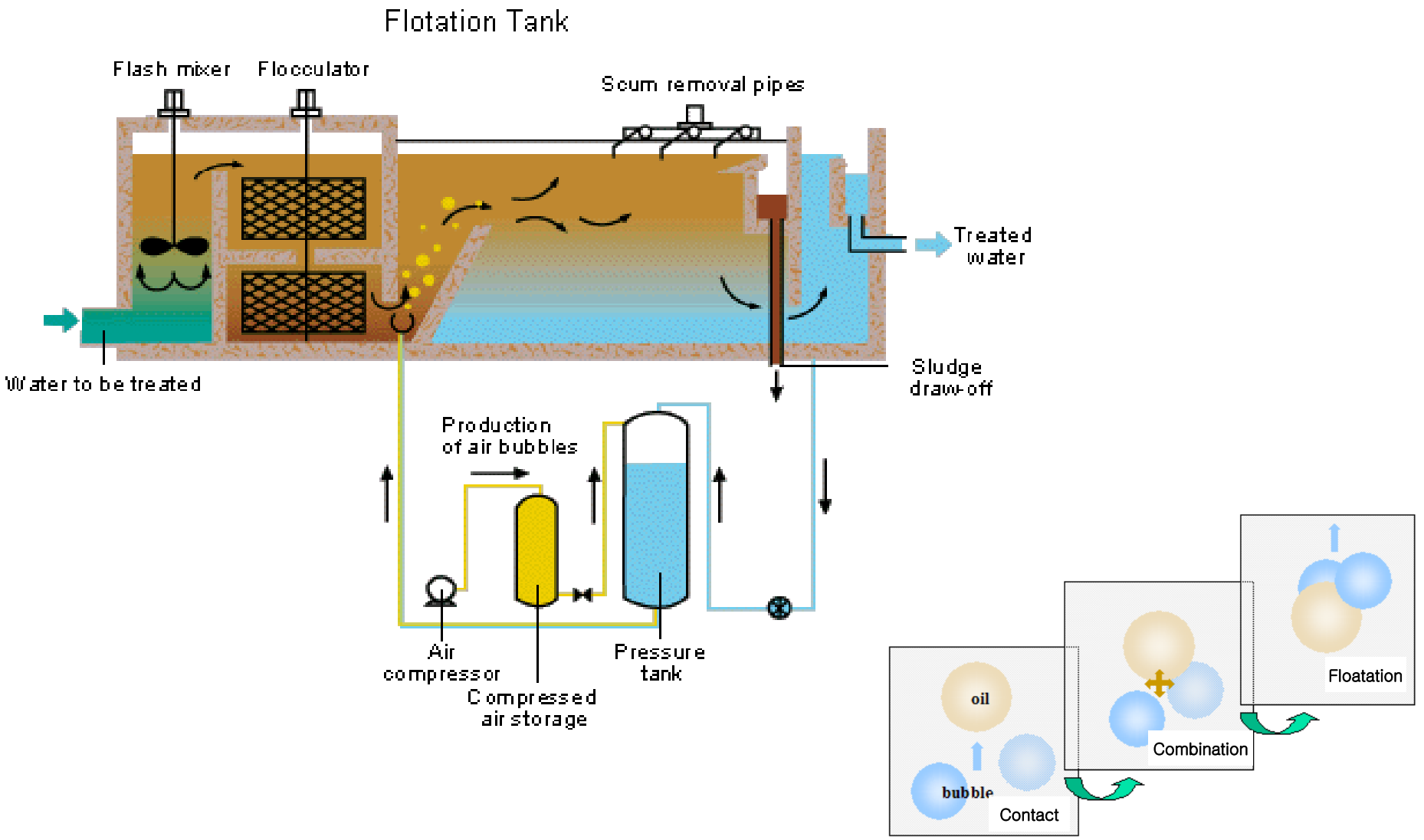
- Foam fractionation

Gas bubbles (MSA)



Recovery of detergent from waste solutions

Water Treatment Using Foam Fractionation

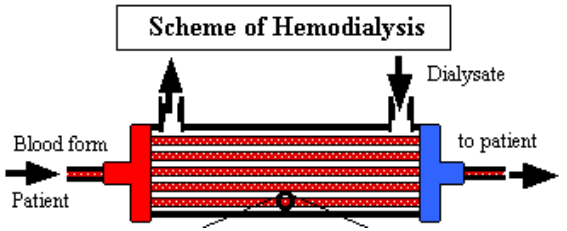


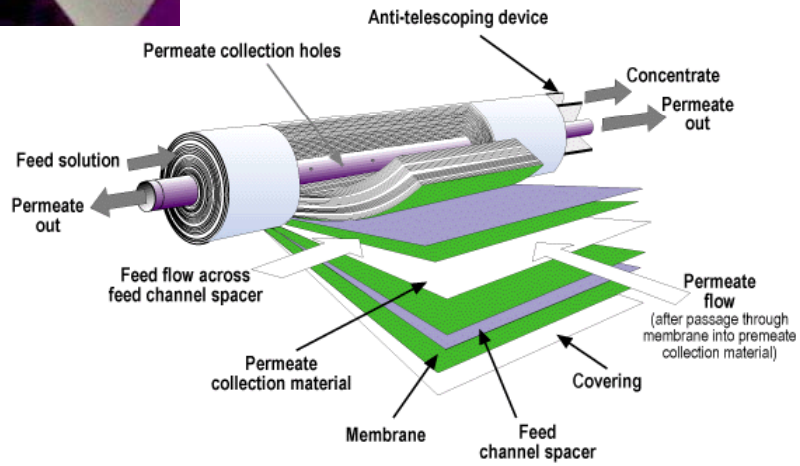
Separation by Barrier

- Use of microporous/nonporous membrane as semipermeable barriers
  - Microporous membrane: different diffusion rates through pores
  - Nonporous membrane: differences in both solubility in the membrane and diffusion rate through the membrane

- Membrane materials
  : Natural fibers, synthetic polymers, ceramics, metals, liquid films

- Fabrication of membrane
  : Flat sheets, tubes, hollow fibers, spiral-wound sheets



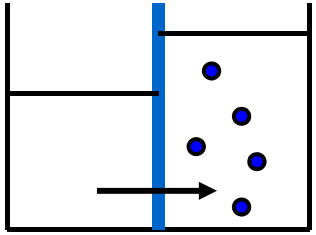


Separation by Barrier

- Osmosis

Nonporous membrane

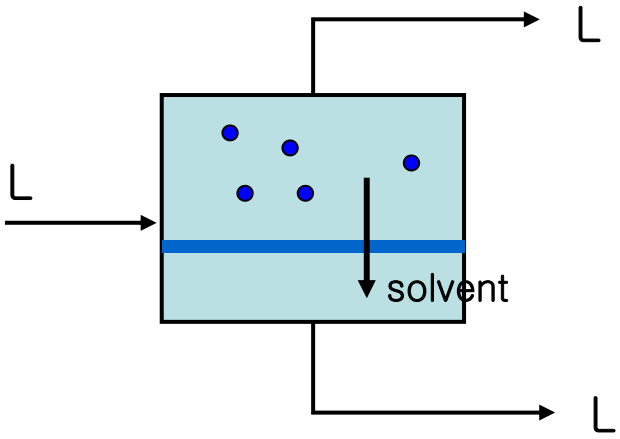
Concentration gradient



- Reverse osmosis

Nonporous membrane

Pressure gradient

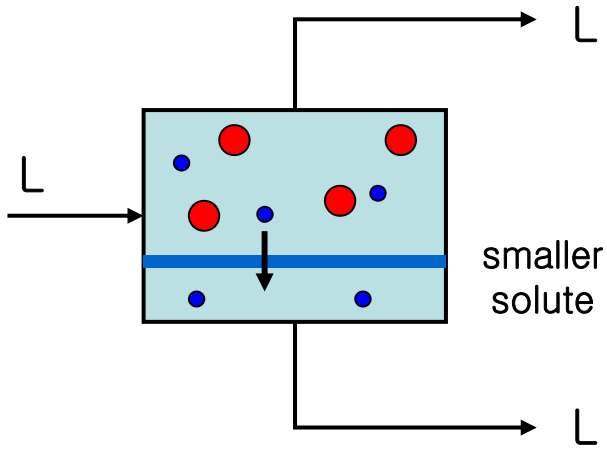


Desalination of sea water

- Dialysis

Porous membrane

Concentration gradient,
Pressure gradient



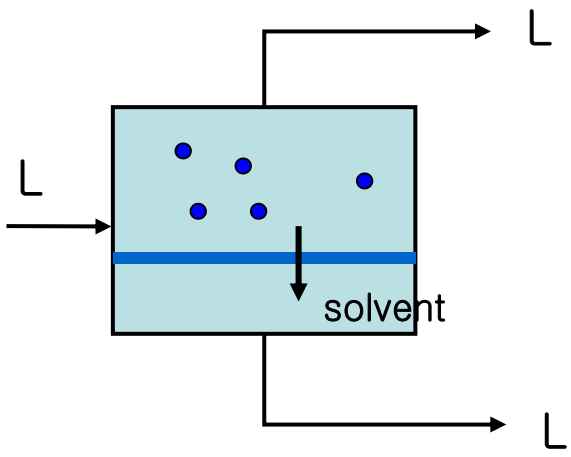
Recovery of caustic
from hemicellulose

Separation by Barrier

• Microfiltration

Microporous membrane

Pressure gradient



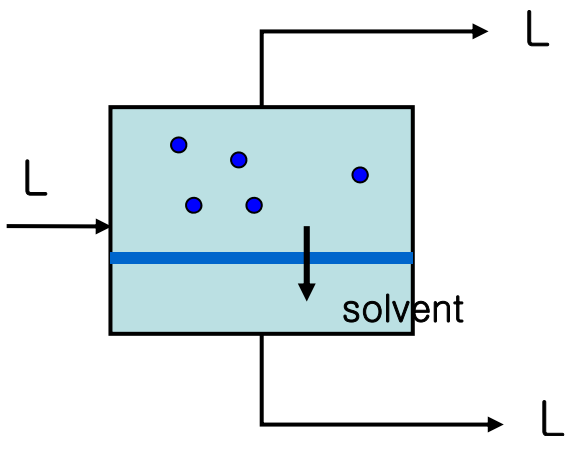
Removal of bacterial from drinking water

(retention of molecules : 0.02 – 10 μm)

• Ultrafilration

Microporous membrane

Pressure gradient



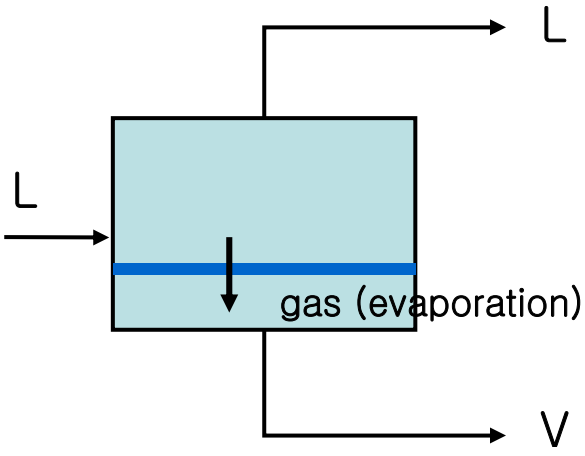
Separation of whey from cheese

(retention of molecules : 1 – 20 nm)

• Pervaporation

Nonporous membrane

Pressure gradient



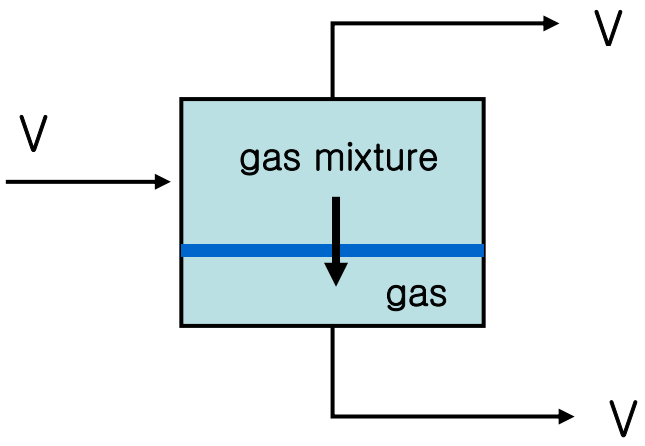
Separation of azeotropic mixtures

Separation by Barrier

- Gas permeation

Nonporous membrane

Pressure gradient

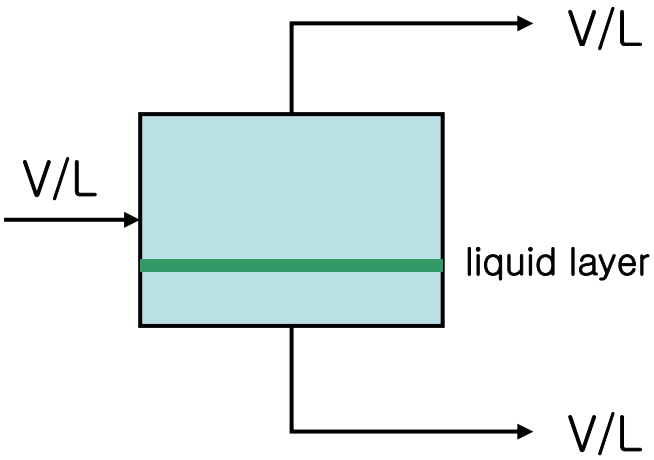


Hydrogen enrichment

- Liquid membrane

Liquid membrane

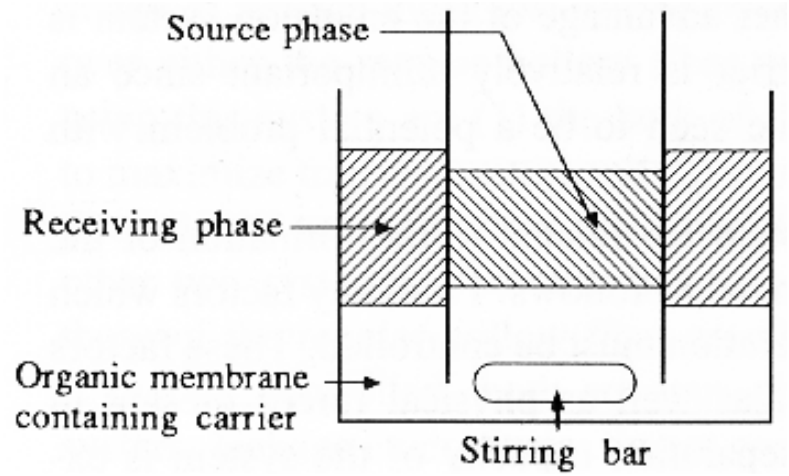
Pressure gradient



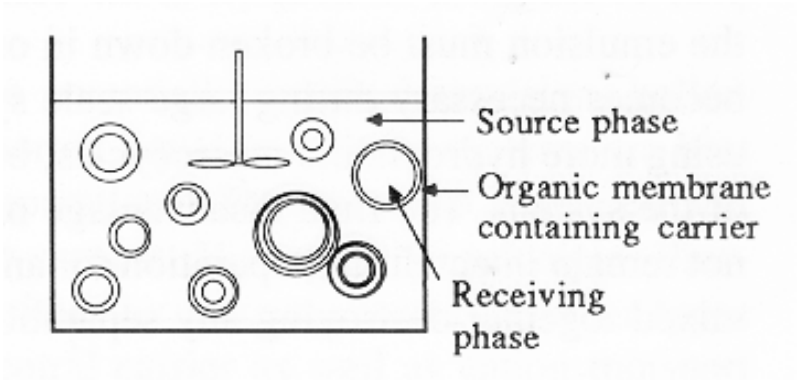
Removal of hydrogen sulfide

Liquid Membrane Types

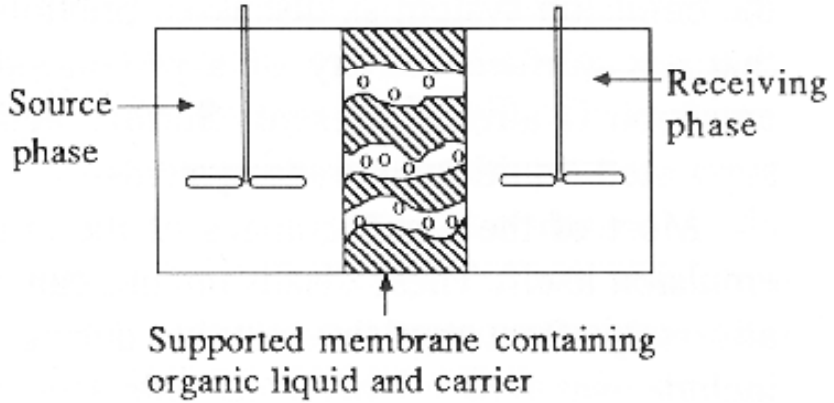
Bulk liquid membrane



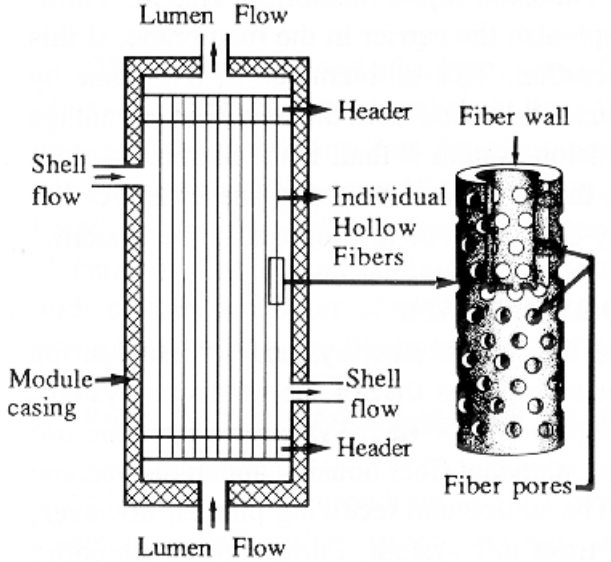
Emulsion liquid membrane



Thin sheet supported liquid membrane



Hollow fiber supported liquid membrane

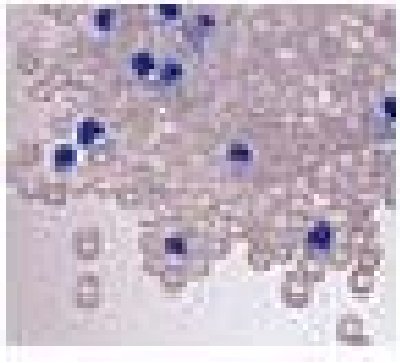


Separation by Solid Agent

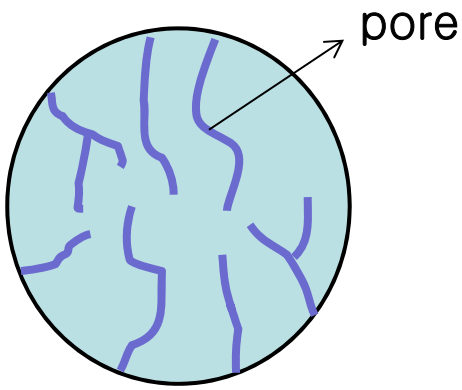
- Solid mass-separating agent
  - Form of a granular material or packing
- Saturation → Periodical regeneration is required
  - Batchwise or semicontinuous operation

Molecular sieve

Activated carbon



Silica gel

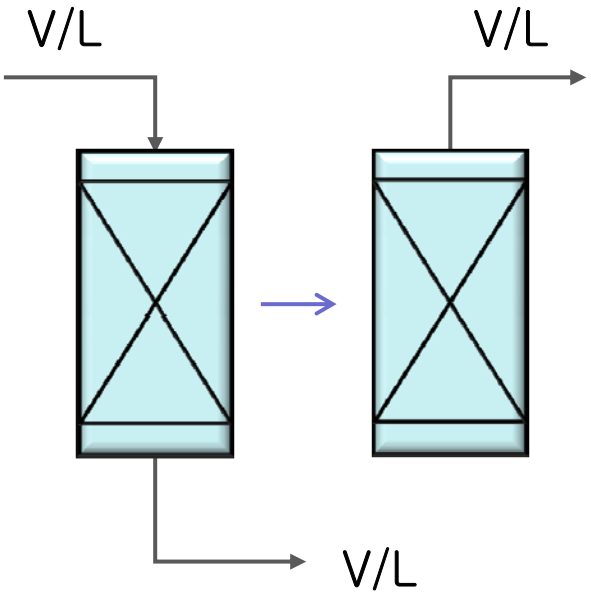


Packed columns

Separation by Solid Agent

- Adsorption

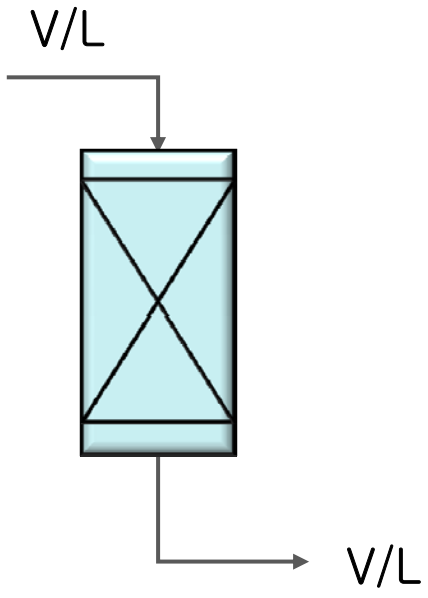
Solid adsorbent



Purification of p-xylene

- Chromatography

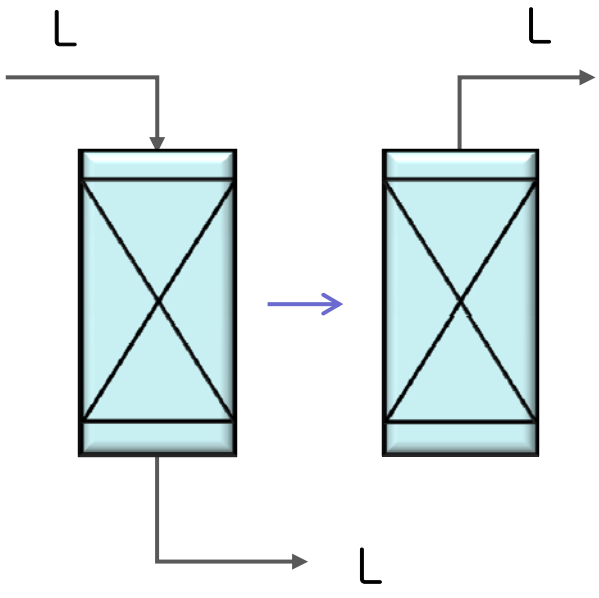
Solid adsorbent or liquid adsorbent on solid support



Separation of xylene isomers and ethylbenzene

- Ion exchange

Resin with ion-active sites



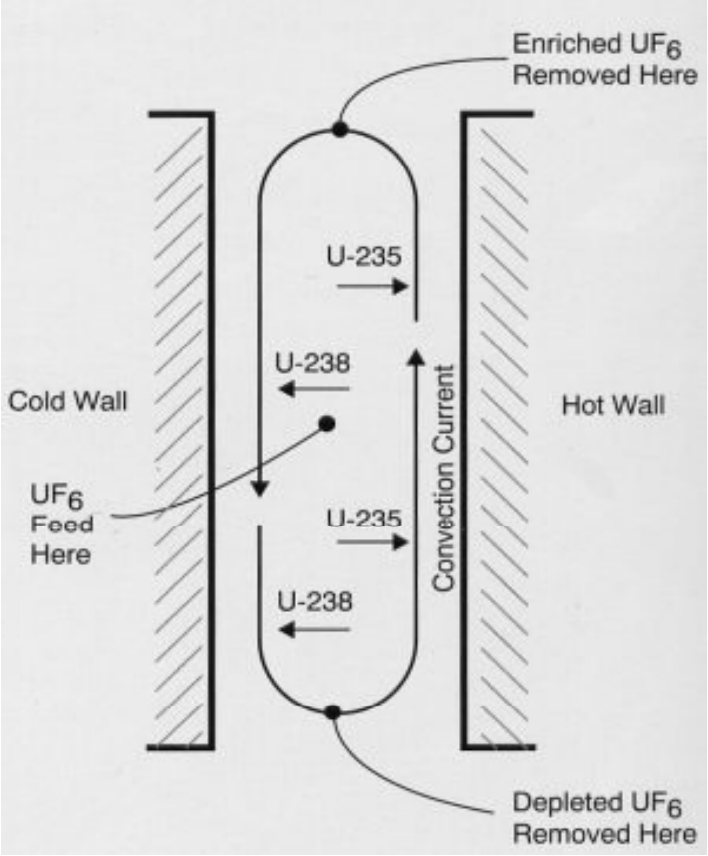
Demineralization of water (removing calcium ions)

Separation by External Field or Gradient

- Different degrees of response of molecules and ions to forces and gradients
- Centrifugation
  - Force field or gradient: Centrifugal force field
    Pressure field → separation according to molecular weight
  - Example: Separation of uranium isotopes,
    separation of plasma from blood

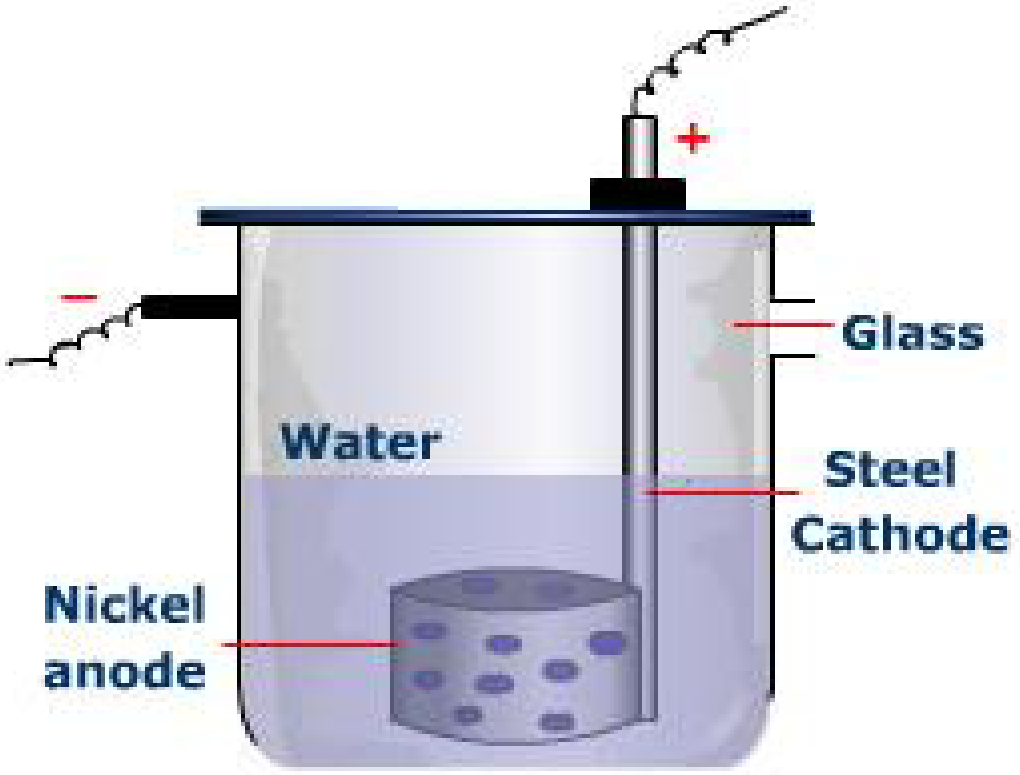
Separation by External Field or Gradient

- Thermal diffusion
  - Force field or gradient: Thermal gradient
  - Example: Separation of uranium isotopes



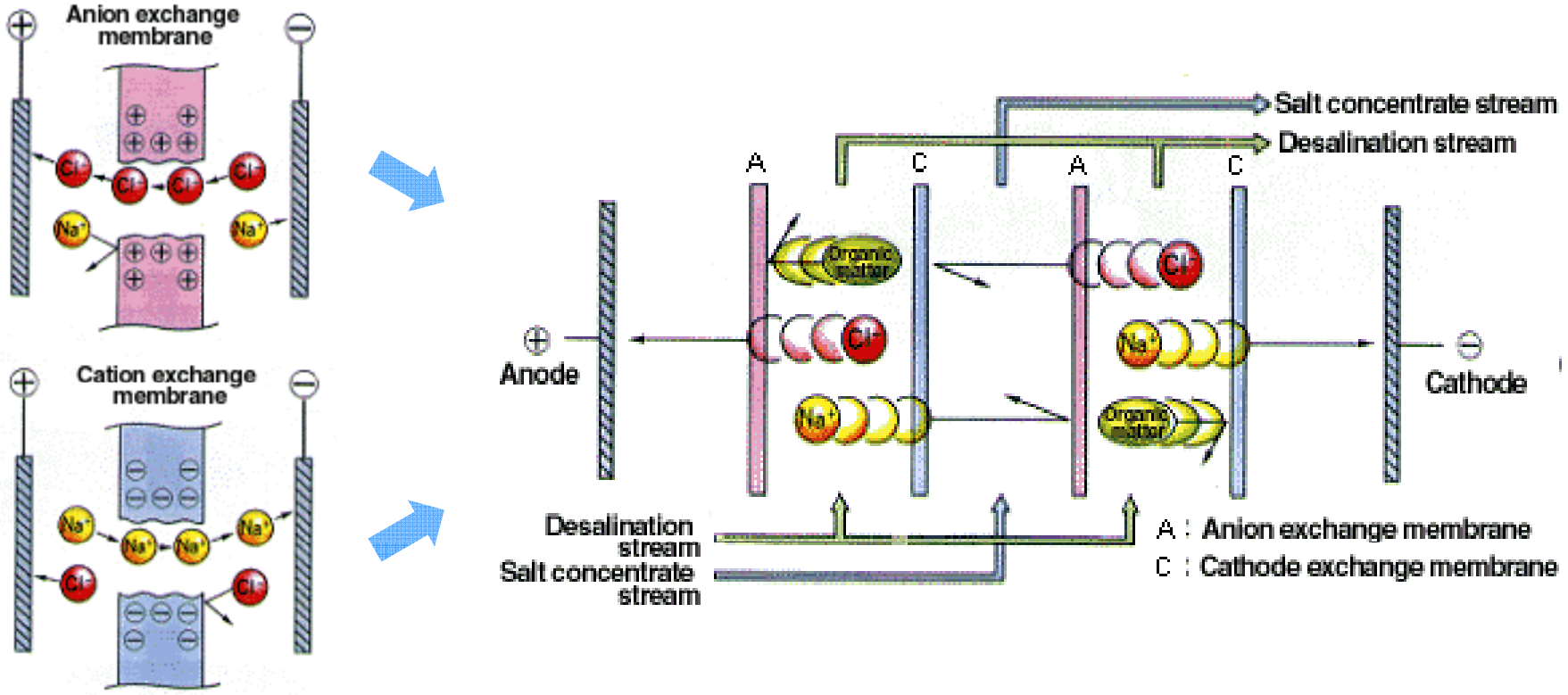
Separation by External Field or Gradient

- Electrolysis
  - Force field or gradient: Electrical force field
  - Example: Concentration of heavy water (D_2O)



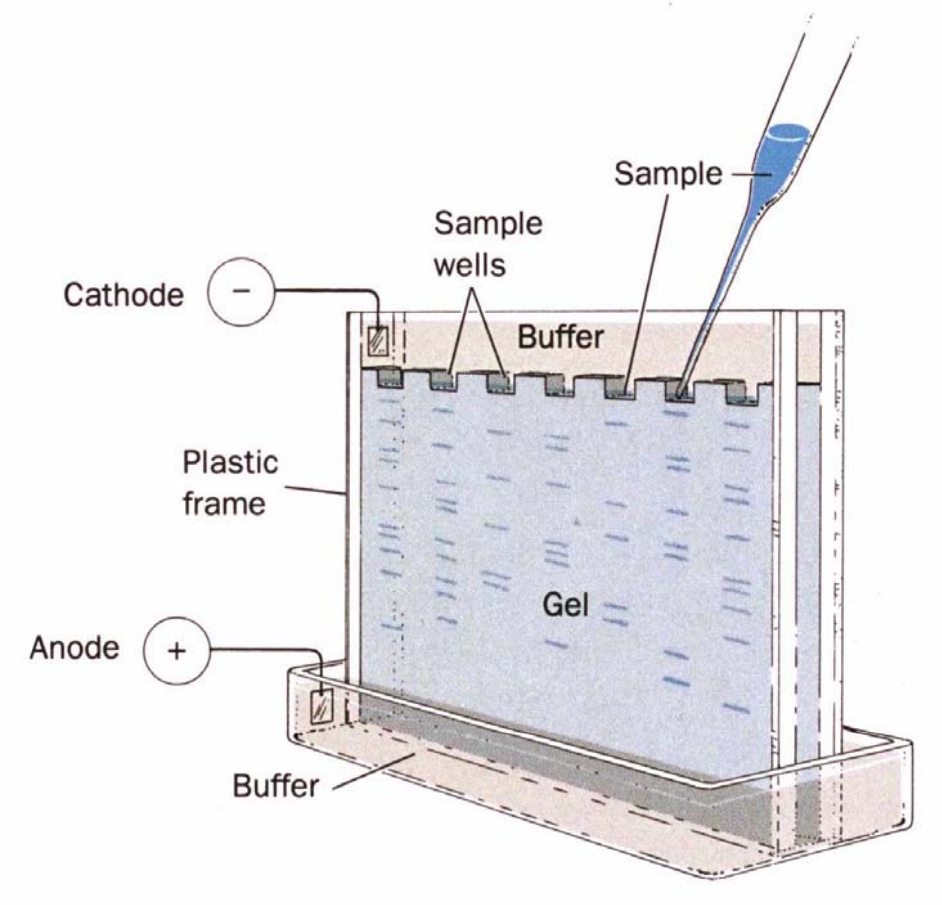
Separation by External Field or Gradient

- Electrodialysis
  - Force field or gradient: Electrical force field and membrane
  - Transport salt ions from one solution through ion-exchange membranes to another solution under the influence of an applied electric potential difference
  - Example: Desalinization of sea water



Separation by External Field or Gradient

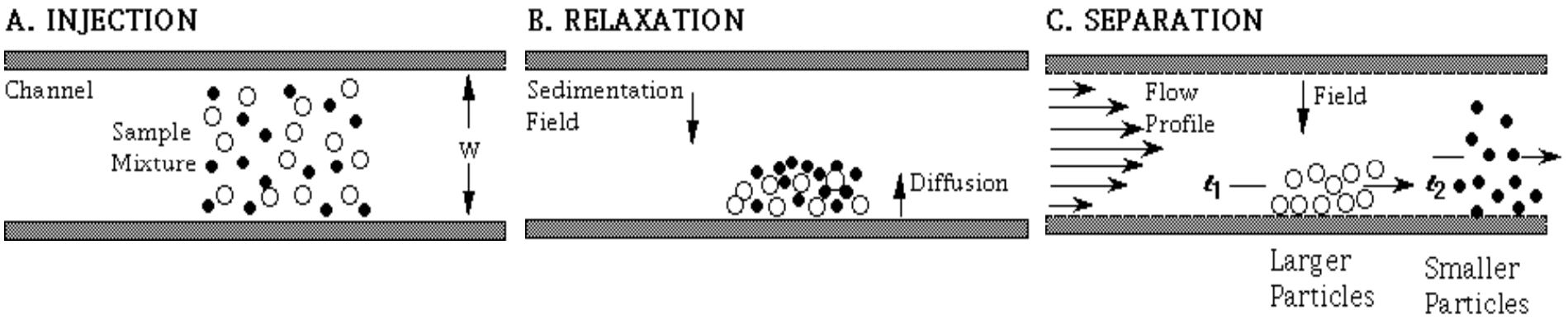
- Electrophoresis
  - Force field or gradient: Electrical force field
  - Example: Recovery of hemicelluloses



- Using different migration velocities of charged colloidal or suspended species in an electric field
- Application : Biochemicals

Separation by External Field or Gradient

- Field–flow fractionation
  - Force field or gradient: Laminar flow in force field
  - An electrical or magnetic field or thermal gradient is established perpendicular to a laminar–flow field



Micromolecular and colloidal materials