Removal of residual particulate and dissolved constituents

Tertiary treatment

- **Further treatment of secondary treatment effluent**
  - To meet standards
  - To reduce loading to the water body
  - For water reuse
- **Removal of residual particulates and/or dissolved constituents**
  - Particulates
  - TDS
  - Refractory organics
  - Nutrients
- **Disinfection – pathogen inactivation** (swimmable water!)

Removal of residual particulates

- **By filtration processes**

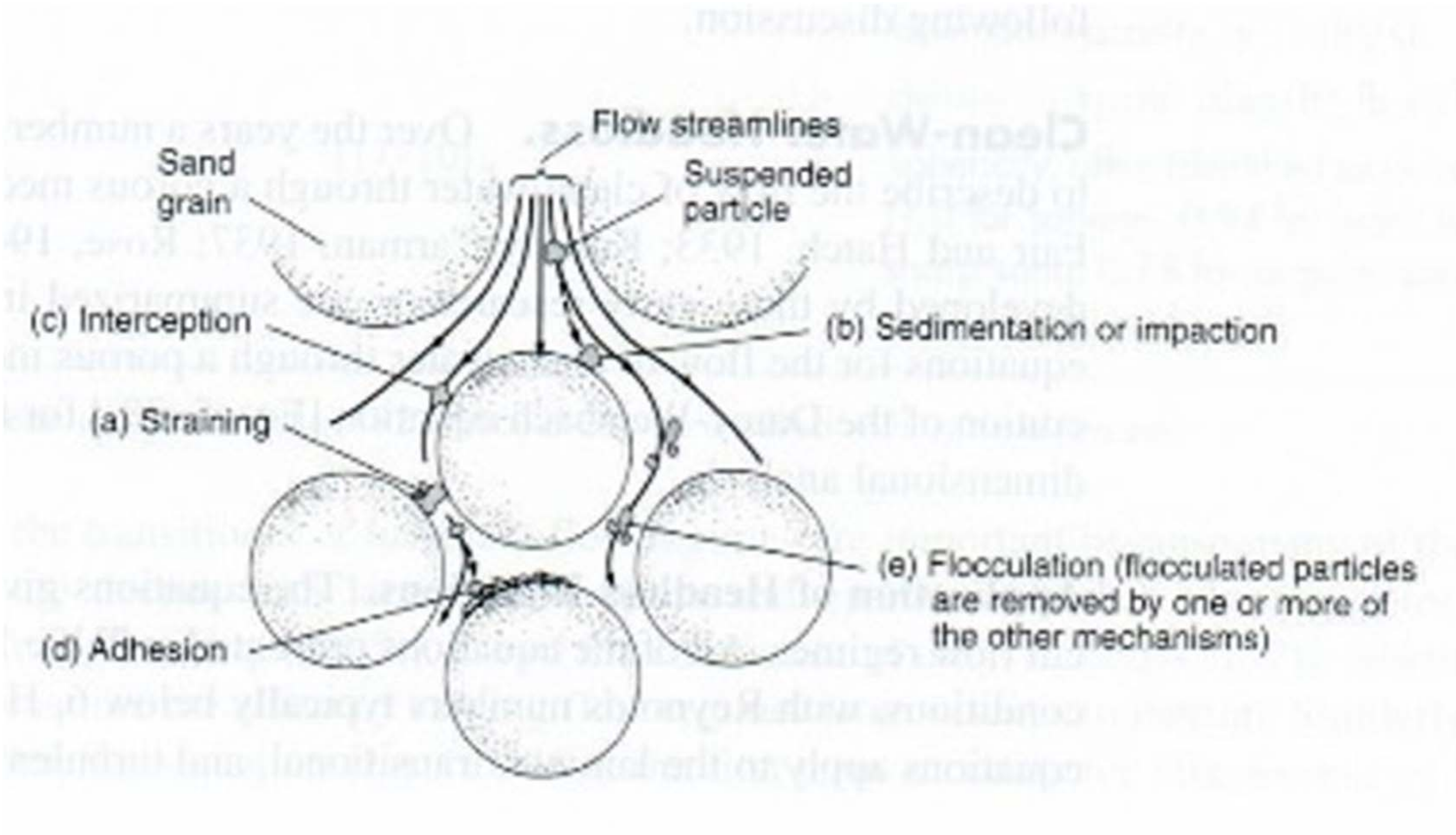
- **Depth filtration**
  - Usually sand filters, anthracite coal, dual- or multi-media

- **Surface filtration**
  - Use fabrics

- **Membrane filtration**
  - Smaller opening size than surface filtration
  - Microfiltration, ultrafiltration, nanofiltration, reverse osmosis

Depth filtration

- **Particle removal mechanisms**

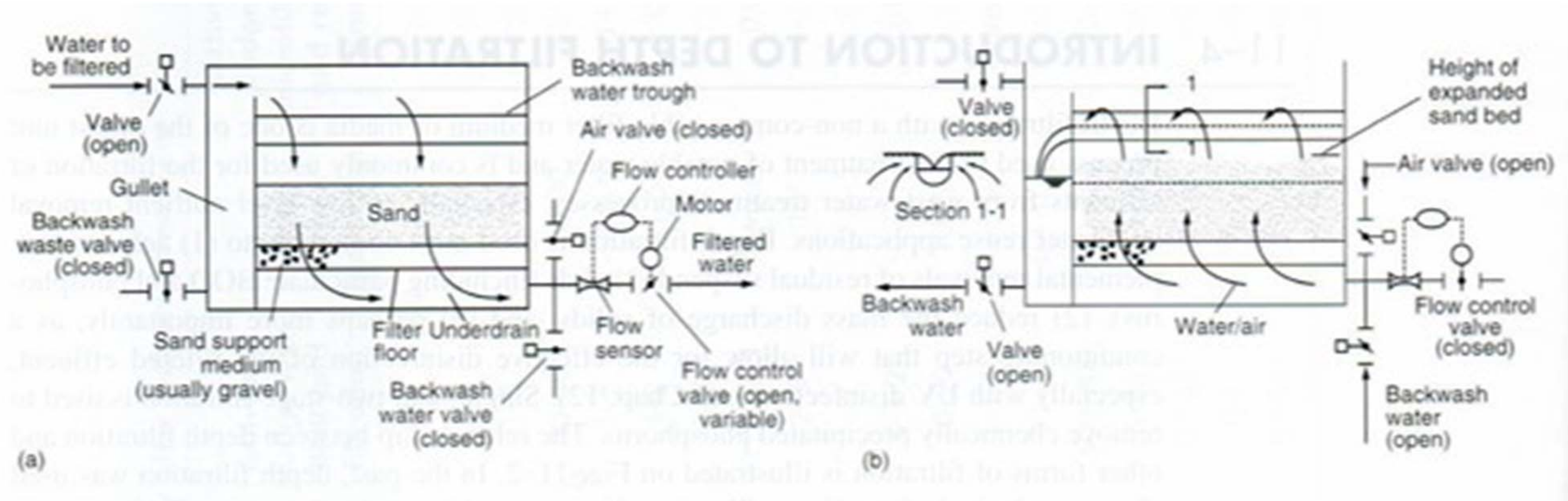


Depth filtration

- **Particle removal mechanisms**
  - **Straining**
    - Mechanical : particles larger than the pore space are strained out mechanically
    - Chance contact: particles smaller than the pore space are trapped within the filter by chance contact
  - **Sedimentation or impaction**
    - Heavy particles that do not follow the flow streamlines are removed when they come in contact with the surface of the filtering medium
  - **Interception**
    - Particles that move along in the streamline are removed when they come in contact with the surface of the filtering medium

Depth filtration

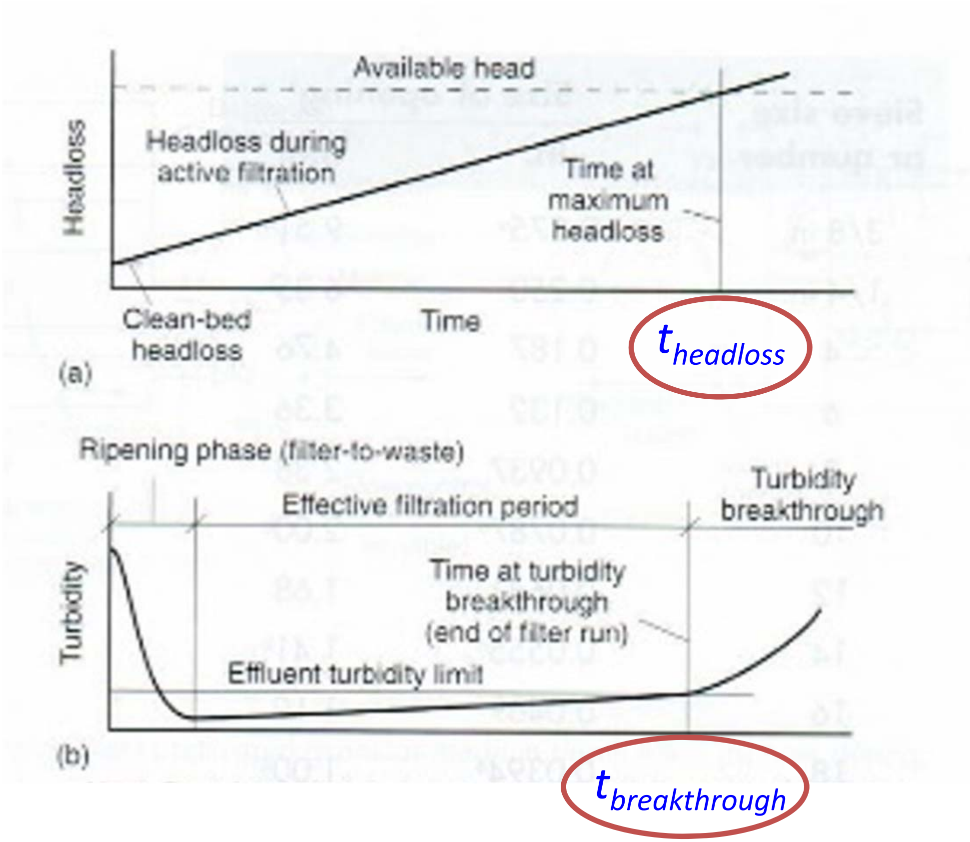
- **Operation of depth filter**
  - **Filtration-backwash cycle**



<Filtration> <Backwash>

Depth filtration

- **Headloss buildup and effluent quality**



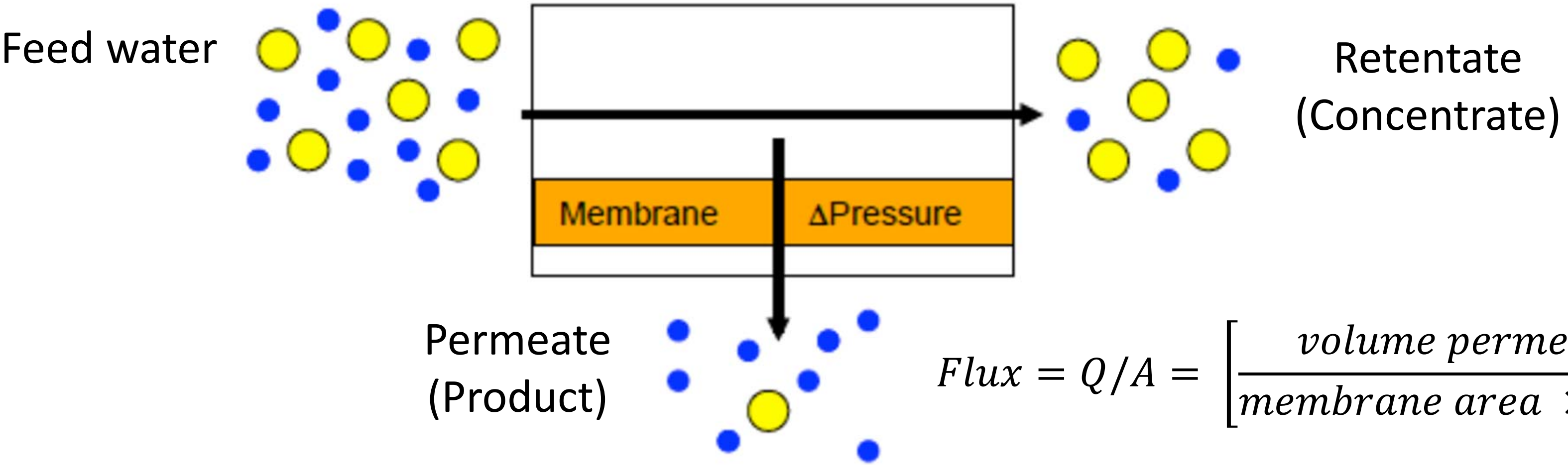
– The shorter of the $t_{headloss}$ and $t_{breakthrough}$ will be the time for backwash cycle

– Optimized design: design the filter such that

$$t_{headloss} \approx t_{breakthrough}$$

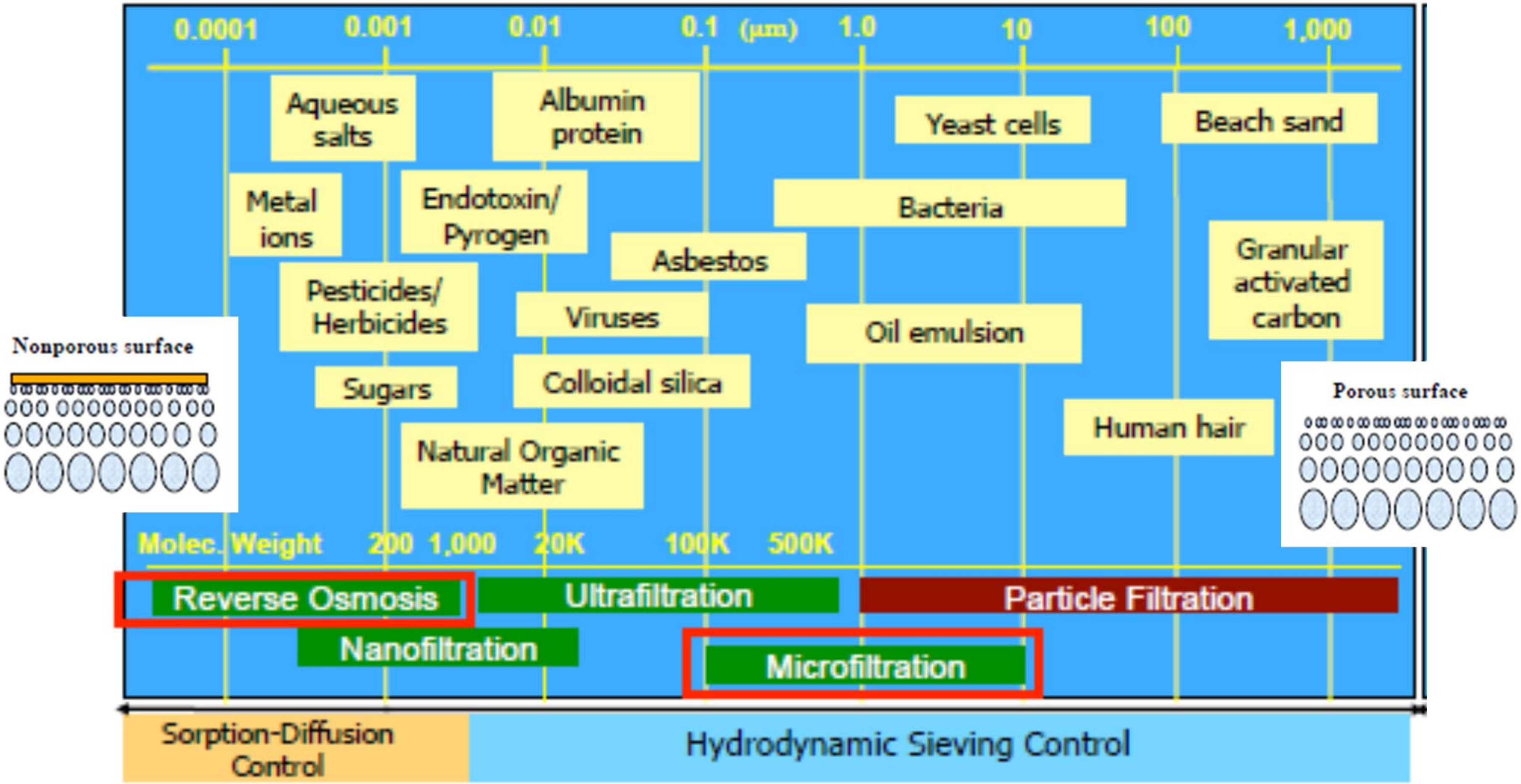
Membrane filtration

- **Terminologies**
  - **Feed water**: influent water supplied to the membrane system for treatment
  - **Permeate**: the liquid that has passed through the membrane
  - **Retentate**: The portion of the feed water that does not pass through the membrane
  - **Flux**: The rate at which permeate flows through the membrane



$$Flux = Q/A = \left[\frac{volume\ permeate}{membrane\ area\ \times time}\right]$$

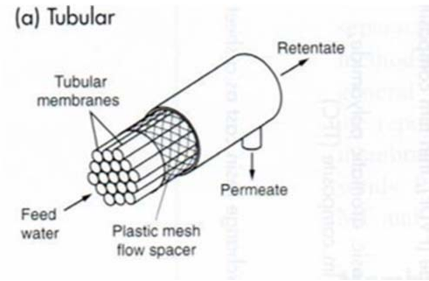
Membrane filtration - classification



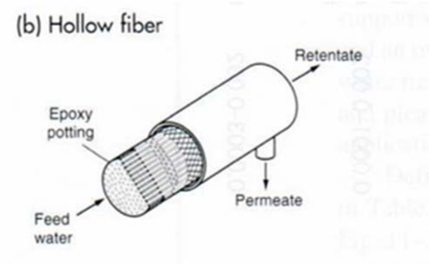
RO/NF: nonporous membrane
Diffusion-like process

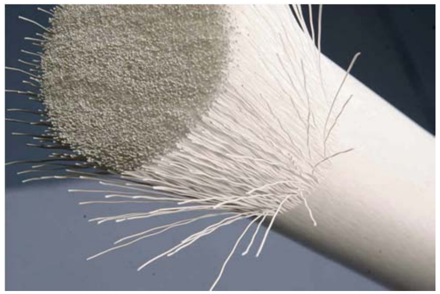
MF/UF: porous membrane
Straining-like process

Membrane configuration



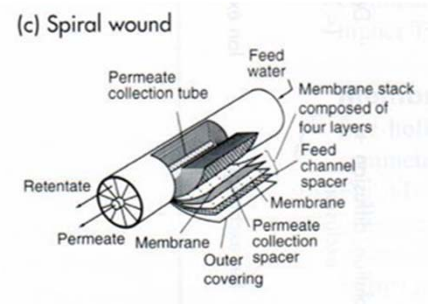
- **Tubular**
  - Membrane is cast on the inside of a support tube and the tubes are placed in a pressure vessel
  - Feed water is pumped through the tube and the permeate is collected outside
  - Tube diameter 6-40 mm

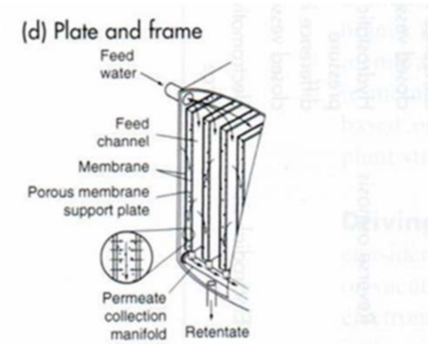


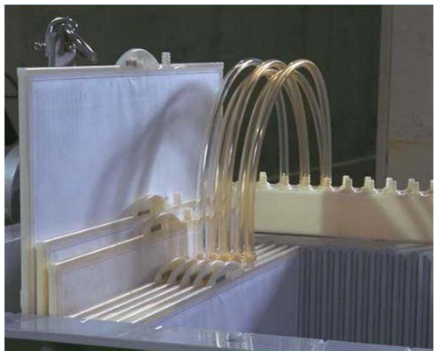


- **Hollow fiber**
  - A module consists of a bundle of hundreds to thousands of hollow fibers
  - Inside diameter 35-45 µm, outside diameter 90-100 µm

Membrane configuration





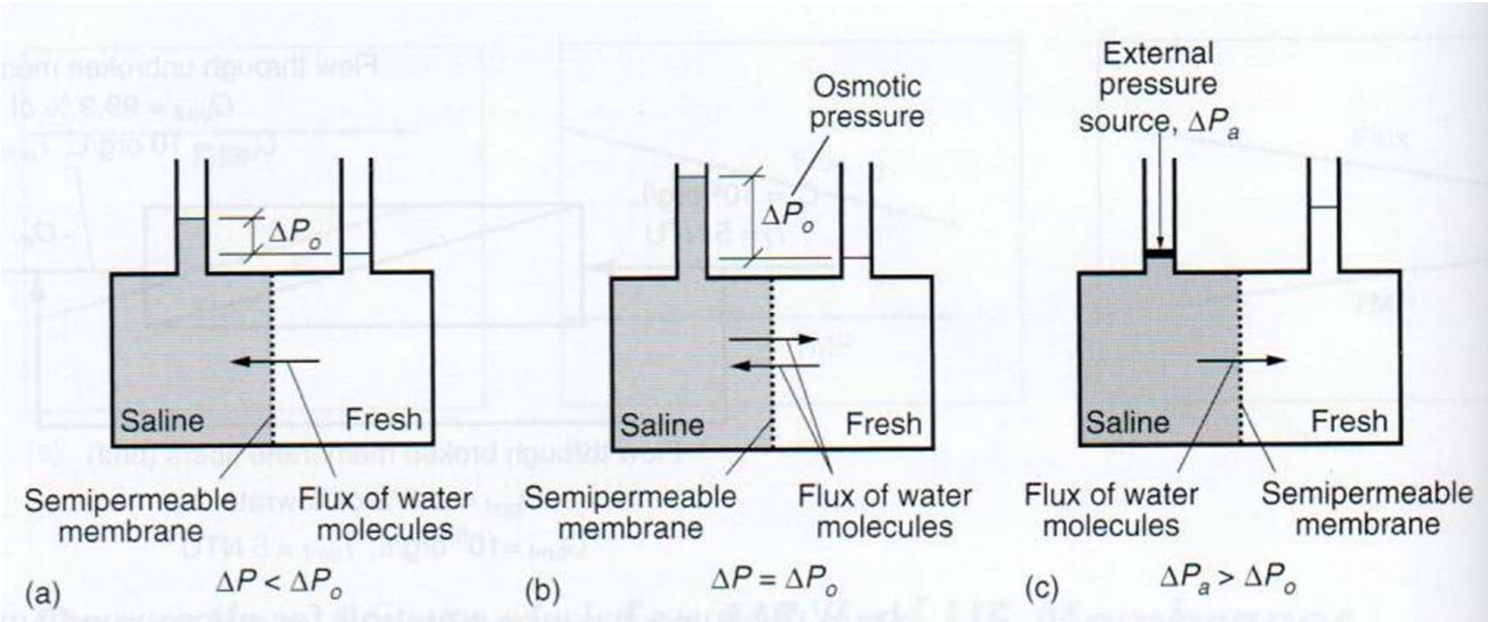


- **Spiral wound**
  - Flat membrane sheets are rolled into a tight circular configuration
  - A flexible permeate spacer is placed between two flat sheets
  - Membrane is sealed on the three side; the open side is connected to a perforated pipe

- **Plate and frame**
  - Consists of a series of flat membrane sheets and support plates
  - The plate supports the membranes and provides a channel for the permeate to flow out of the unit

Driving force: pressure

- **Reverse osmosis**
  - Produces retentate (concentrate) that usually has x2 or more salt concentration than the feed water



Osmosis
Water moves from low salt conc. → high salt conc.

Osmotic equilibrium
No net water movement

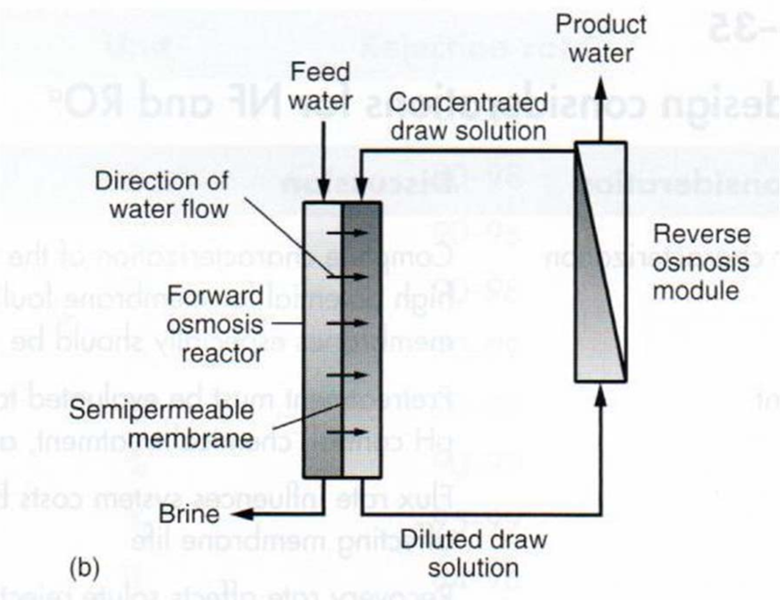
Reverse osmosis
Water moves from high salt conc. → low salt conc.

Membrane fouling

- **Particulate fouling**
  - Particles clog the membrane pores
- **Scaling**
  - As chemical constituents in the feed water are removed at the surface of a membrane, their local concentration increases
  - Concentrations of some of the constituents will increase beyond their solubility limits and will be precipitated on the membrane surface
  - Especially critical for RO
- **Organic fouling**
  - Many natural organic matter (NOM) are sticky – accumulate on the membrane surface
  - Fouling is accelerated by forming stable organic/inorganic particulate matter
- **Biological fouling**
  - Elevated concentrations of organic matter and nutrients on the membrane surface → favorable for microbial growth
  - Biofilm formed on the membrane surfac

Forward osmosis

- **A membrane technology getting recent interest**
  - RO: High energy consumption for pressurizing the feed water
  - **FO: Uses natural osmotic pressure with minimal pressure application**
  - **<u>Use a more concentrated solution</u> (draw solution) to recover water from the feed water**
  - Principal requirement of the draw solution
    - Osmotic pressure should be greater than the feed solution
    - Must be easy to reconcentrate after being diluted by the water from the feed solution
    - NaCl is a common salt used for draw solution: easy to reconcentrate, no scaling problems



Adsorption

- **Removal of substances in solution by accumulation of those substances on a solid phase**
  - Adsorbate: the substance that is being removed from the solution
  - Adsorbent: the material onto which the adsorbate accumulates

- **Applications**

  Removal of:

    - refractory organics
    - residual inorganic constituents (nitrogen, sulfides, heavy metals, etc.)
    - odor compounds

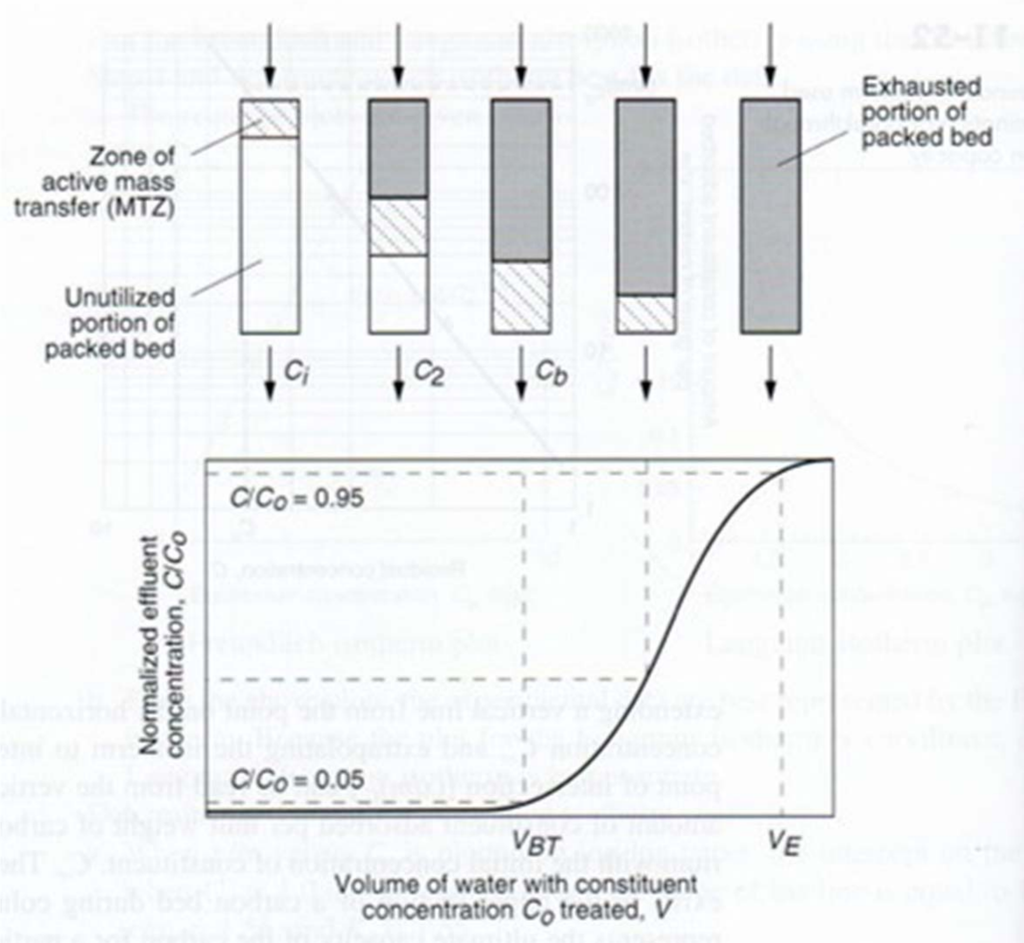
Types of adsorbents

- **Activated carbon**
  - **Most common** – removal of refractory organics & residual COD
  - Derived by i) pyrolysis of organic materials (wood, coal, coconut, etc.) and ii) activation by steam or CO_2 at high temperatures
  - Two types based on particle size
    - GAC (granular activated carbon): > 0.1 mm, apply in columns
    - PAC (powdered activated carbon): < 0.074 mm, apply in well-mixed contact tanks

- **Granular ferric hydroxide**
  - Ferric hydroxides/oxides have high affinity to many metals and metalloids
  - Applicable for removal of arsenic, chromium, selenium, copper, etc.

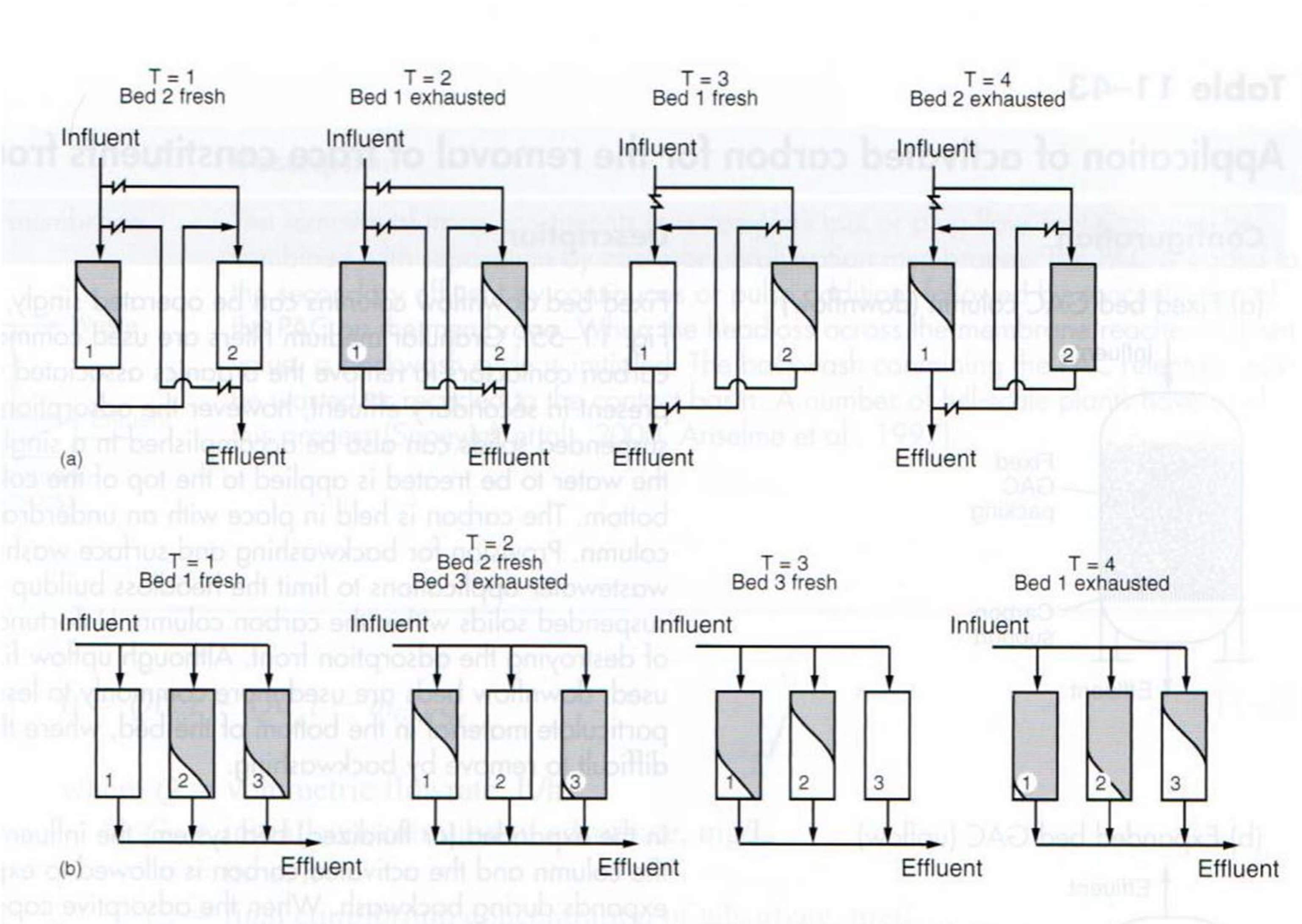
- **Activated alumina**
  - May be considered in case of water reuse
  - Removal of arsenic and fluoride

GAC columns: breakthrough curve



- **Mass transfer zone** (MTZ; dashed zone): adsorption is occurring, some adsorbate conc. in pore-water
- Grey zone: GAC exhausted (adsorption equilibrium with influent), no further adsorption
- **Breakthrough** occurs after adding V_{BT} of influent, but **want full usage of the column**!

GAC columns: configurations



Gas stripping

- **Mass transfer of a gas from the liquid phase to the gas phase**

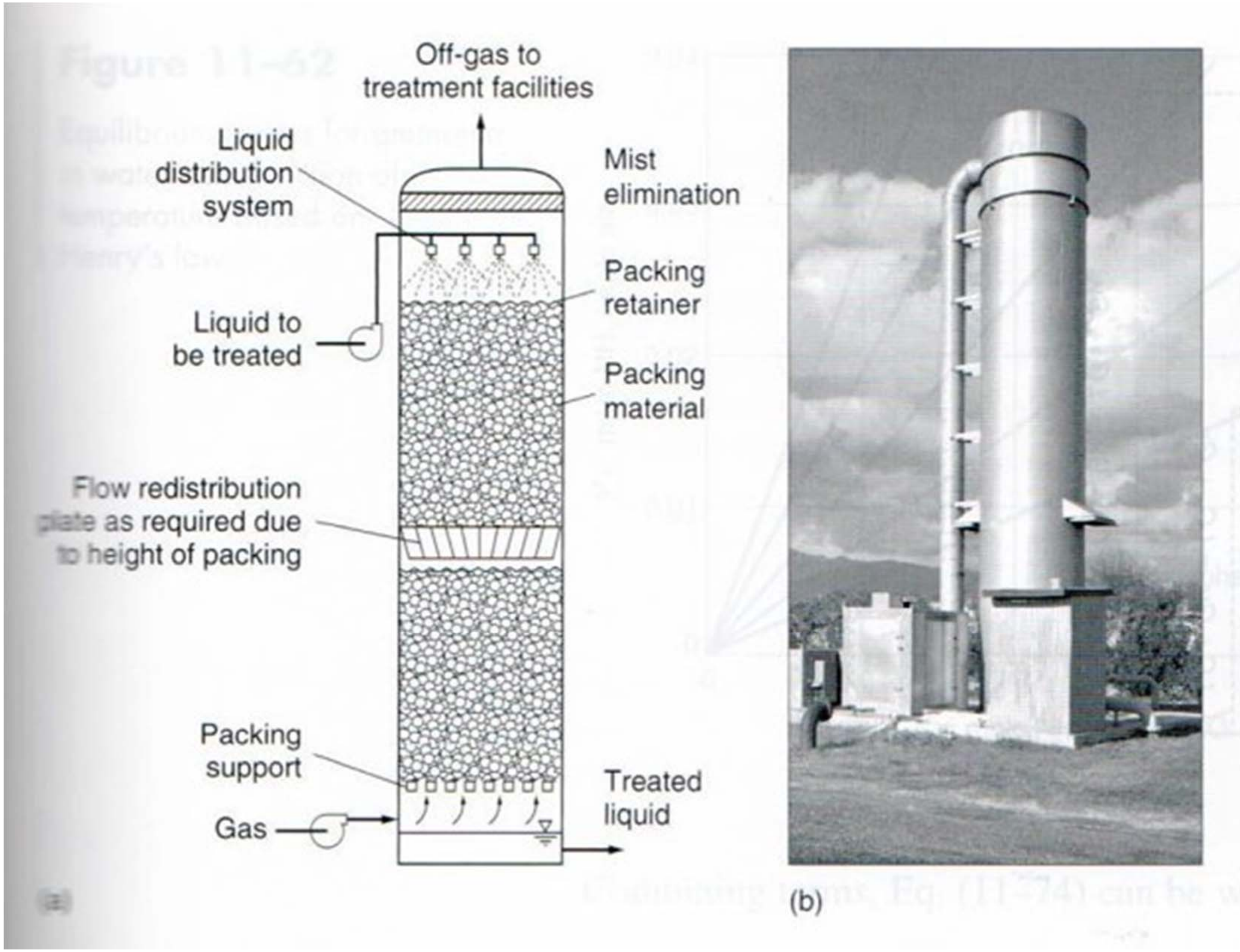
Recall: $$\frac{dC}{dt} = K_L \frac{A}{V}(C - C_s) = K_L a(C - C_s)$$

(for desorption of gas)

- **Stripping (blowing) a contaminant-free gas into the water**
  - Creates large gas-liquid interfacial area for mass transfer
    - Most significant concern in the process design
  - Concentration gradient generated: $C_s \rightarrow 0$

- **Removal of NH_3, odorous gases and VOCs**
  - For ammonia stripping, pH should be raised by addition of lime (why?)

Gas stripping



Ion exchange

- **A unit process in which ions of a given species are displaced from an insoluble exchange material by ions of a different species in solution**
- **So ions in the solution is exchanged by other ions originating from the insoluble exchange material**
- **Applications**
  - Most common: water softening (Na^+ from exchange material to solution; Ca^{2+} and Mg^{2+} from solution to exchange material)
  - Removal of nitrogen, heavy metals, and TDS

Ion exchange

- **Exchange materials**
  - Naturally occurring materials: zeolite (clinoptilolite)
  - Synthetics material: resins, phenolic polymers

- **Nitrogen removal**
  - Remove NH_4^+ or NO_3^-
  - NH_4^+: zeolite or synthetic cation exchange resins
  - NO_3^-: synthetic anion exchange resins

- **Heavy metal removal**
  - Zeolites, synthetic anion and cation resins, chelating resins
  - Some chelating resins are made to have a high selectivity for specific metals (cations – Cu, Ni, Cd, Zn, …)