Physical unit processes II

Physical unit processes II

Physical processes used for solid/liquid separation

- Depth filtration
- Membrane filtration
- Flotation

Mixing

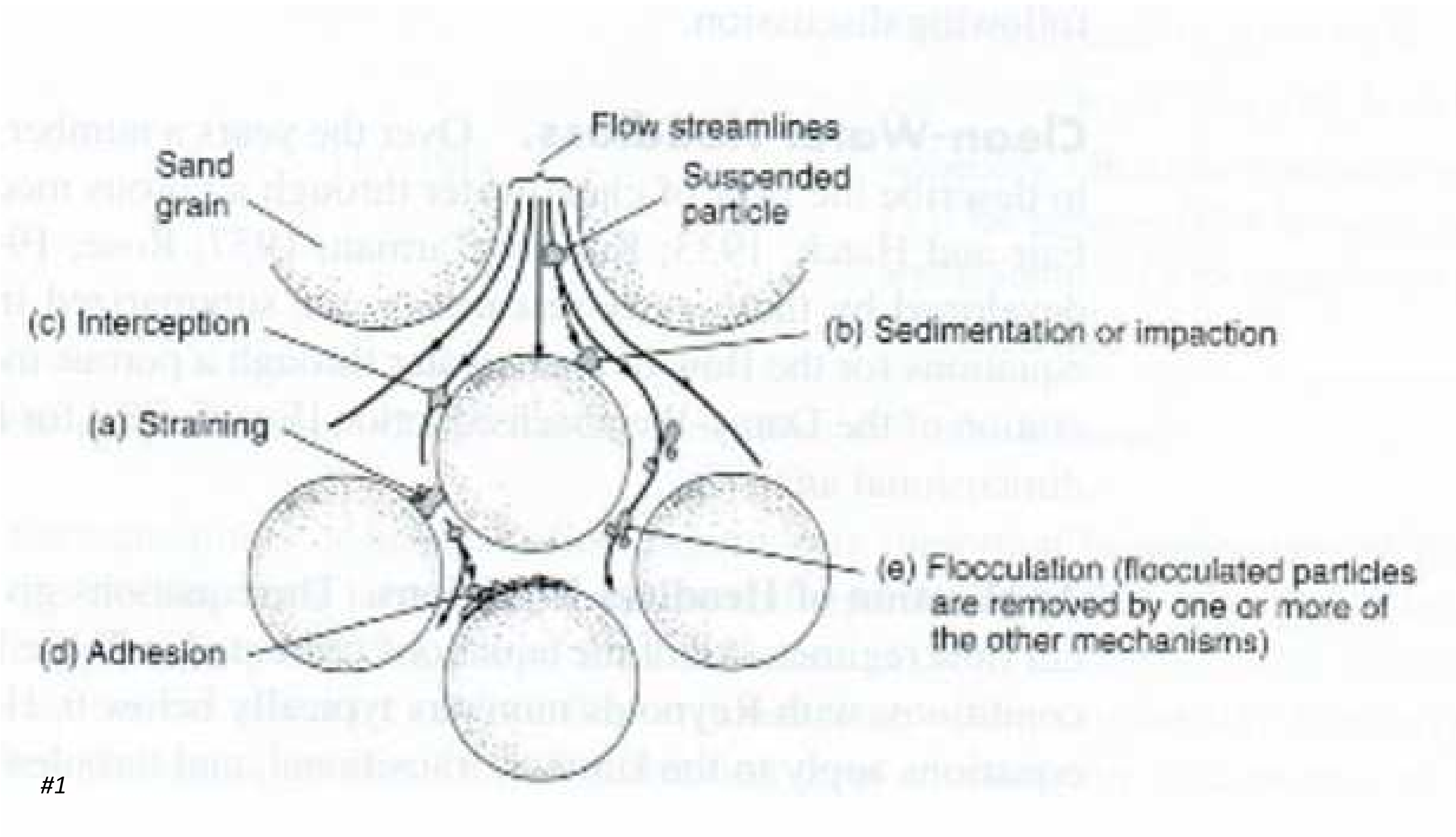
- Fundamentals
- Types of mixers

Filtration

- **Often applied as a tertiary (advanced) treatment method to further treat the secondary treatment effluent in order to**
  - meet standards
  - reduce loading to the water body
  - reuse the treated water [e.g., recreational use, toilets, (indirect/direct) potable use]

- **Depth filtration**
  - Usually sand filters, anthracite coal, dual- or multi-media
- **Membrane filtration**
  - Smaller opening size than surface filtration
  - Microfiltration, ultrafiltration, nanofiltration, reverse osmosis

Depth filtration - Particle removal mechanisms



#1

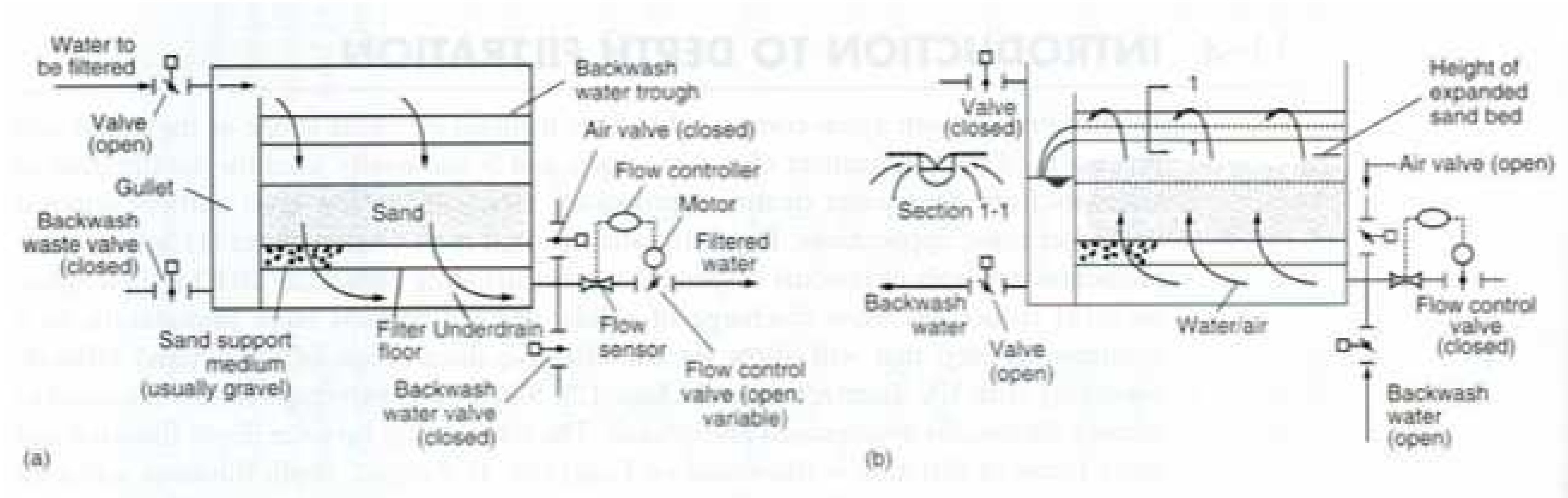
Depth filtration - Particle removal mechanisms

- **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

Operation of depth filter

- **Filtration-backwash cycle**

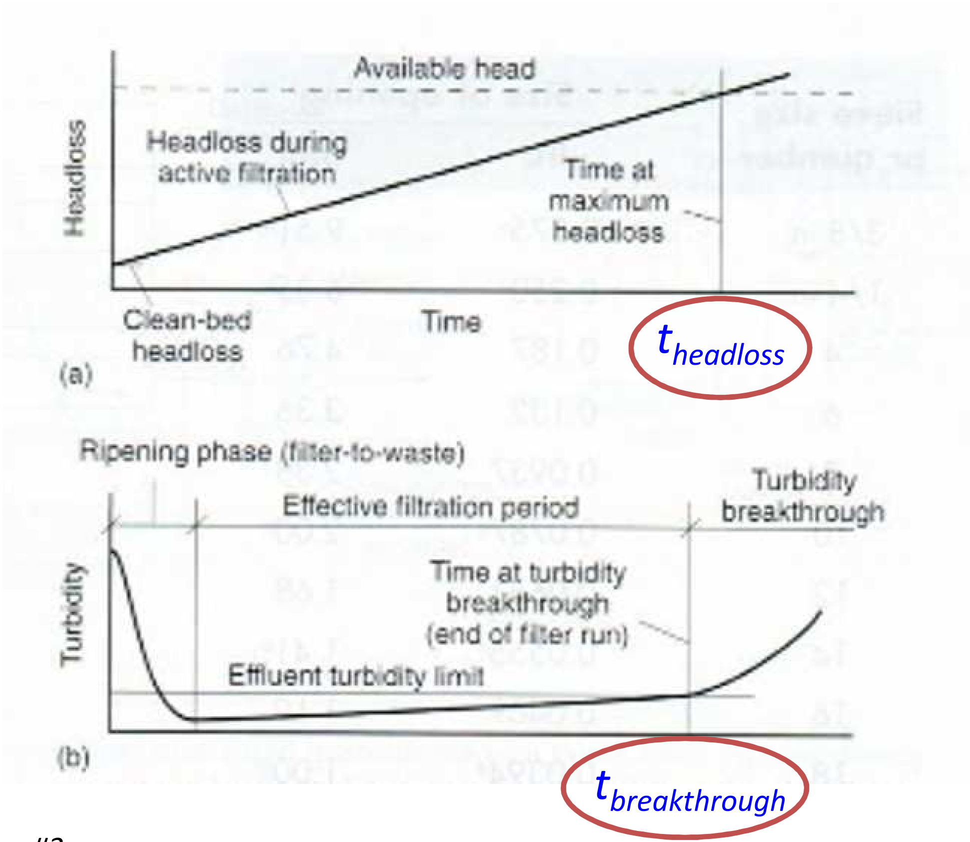
#2



<Filtration> <Backwash>

Headloss buildup and effluent quality

- **Headloss buildup and effluent quality**



#3

- 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

- **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

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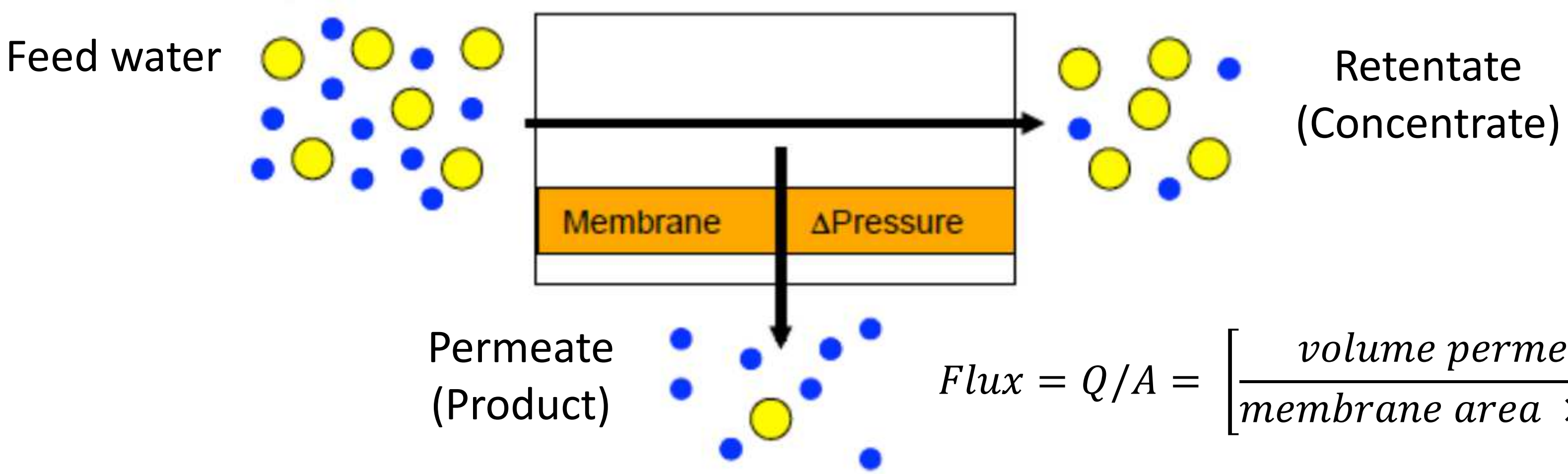
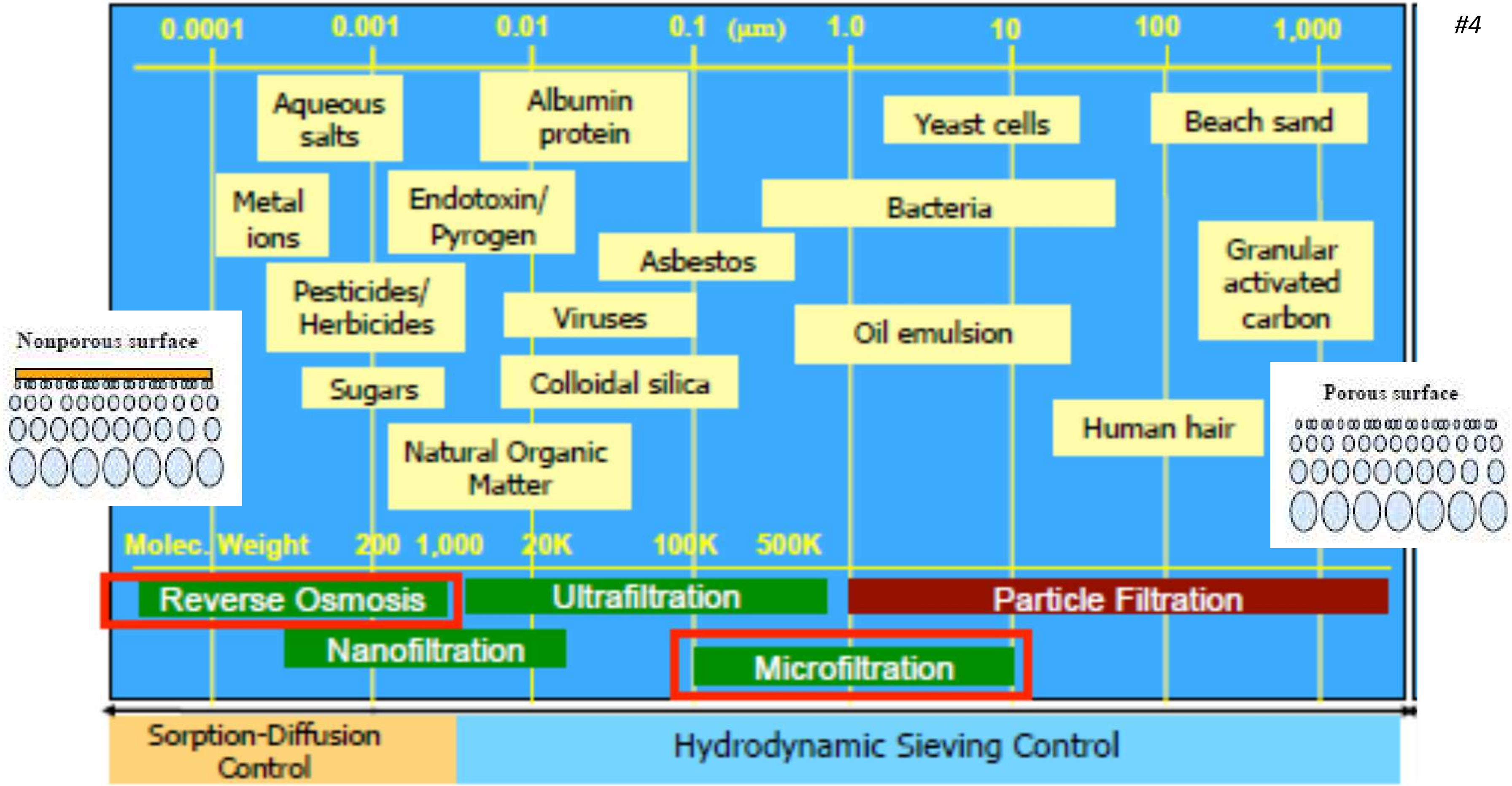


$$Flux = Q/A = \left[\frac{volume\ permeate}{membrane\ area\ \times time}\right]$$

Membrane filtration - classification



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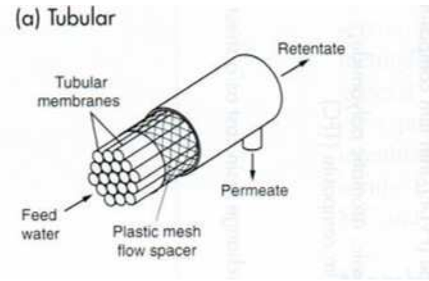
RO/NF: nonporous membrane
Diffusion-like process

MF/UF: porous membrane
Straining-like process

#5



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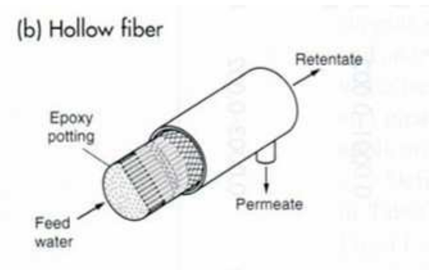

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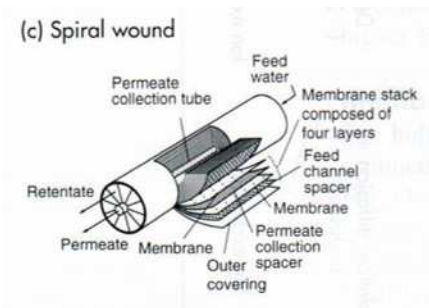
Membrane configuration (1)

- **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 (2)

#5

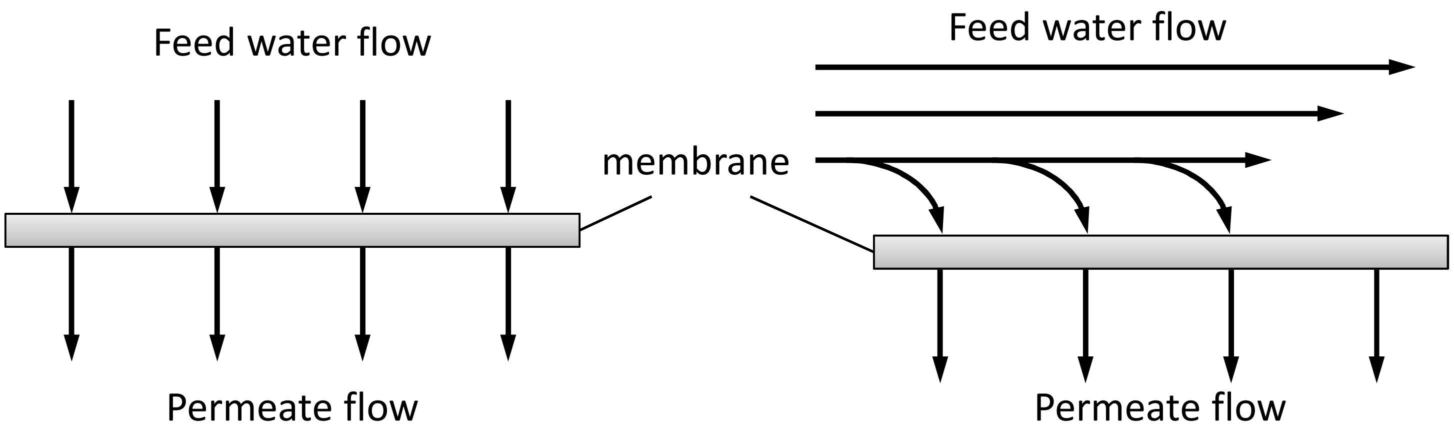


#8

- **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

Driving force: pressure

- Apply either hydraulic pressure or vacuum
- MF & UF: cross-flow or dead-end modes
  - **Cross flow mode**
    - The feed water is pumped parallel to the membrane surface (at a high velocity to control fouling by the shear force)
  - **Dead-end mode**
    - The feed water is directed toward the membrane surface
    - All water applied to the membrane passes through the membrane



Reverse osmosis

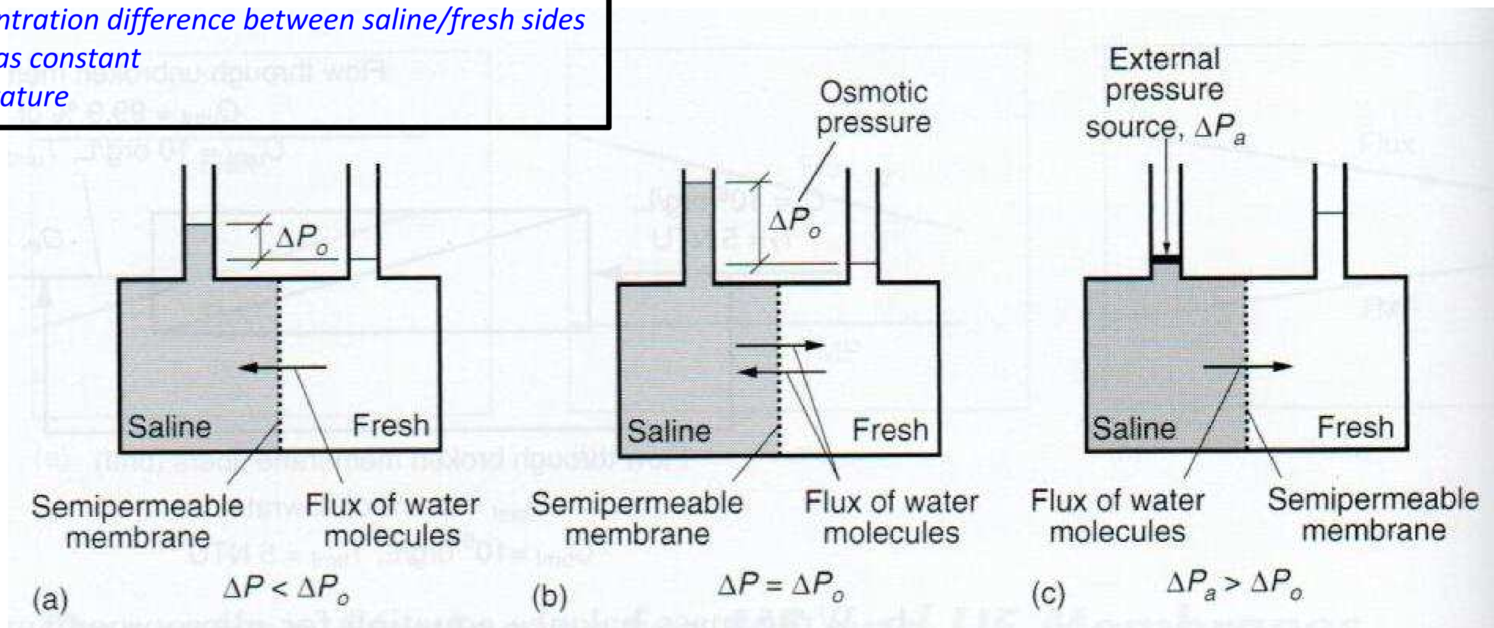
- **Produces retentate (concentrate) that usually has x2 or more salt concentration than the feed water**

Osmotic pressure

$$\Delta P_o \approx \Delta c \cdot RT$$

Δc = concentration difference between saline/fresh sides
R = ideal gas constant
T = temperature

#9



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

Osmotic equilibrium
No net water movement

<u>Reverse osmosis</u>
Water moves from high salt conc. → low salt conc.

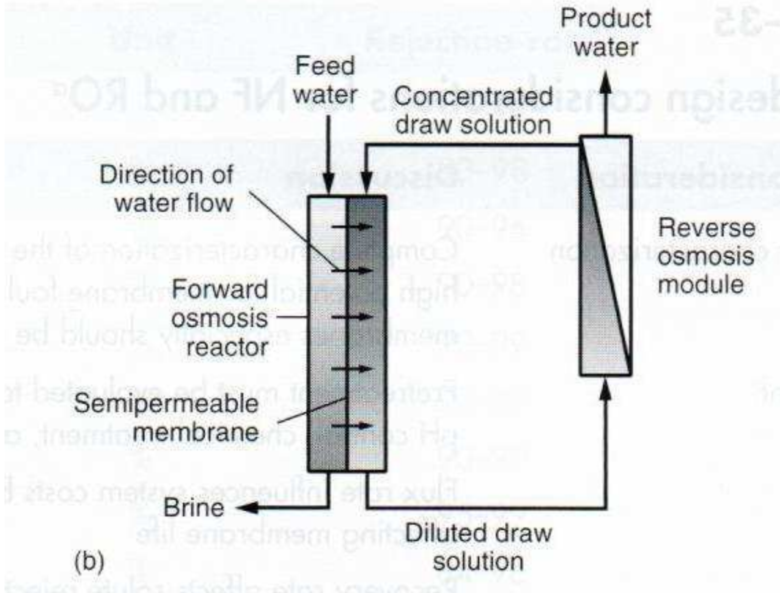
Membrane fouling

- **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 surface

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

#10



Types of flotation unit processes

- **Two typical types of flotation**
  - Dissolved-air flotation
  - Dispersed-air flotation

- **Dissolved-Air Flotation (DAF)**
  - Air is dissolved in the wastewater under a pressure of several atms (high P → high gas solubility)
  - The gas-laden wastewater then flows to a flotation tank under atmospheric pressure (low P → low gas solubility → generation of fine bubbles)

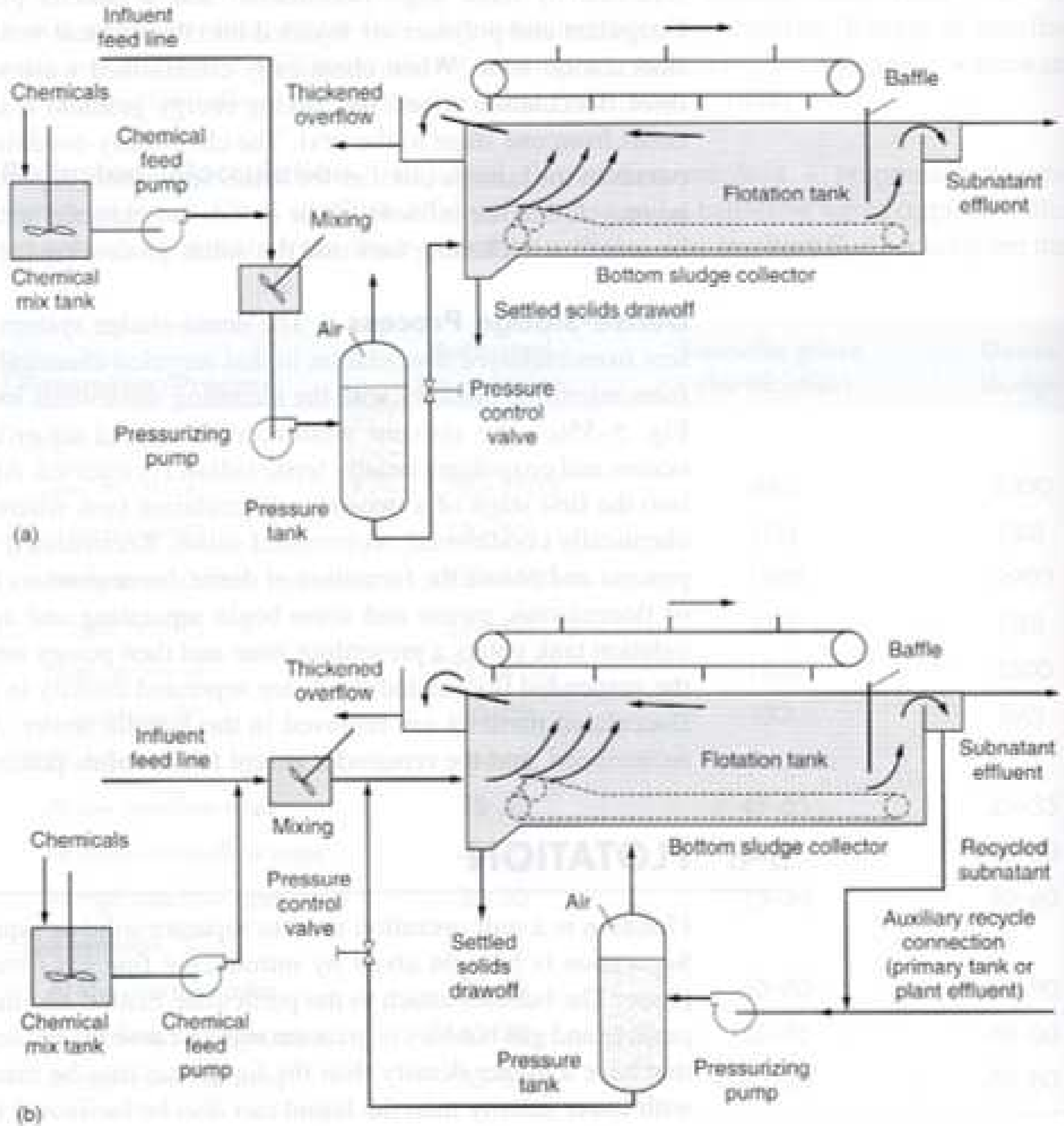
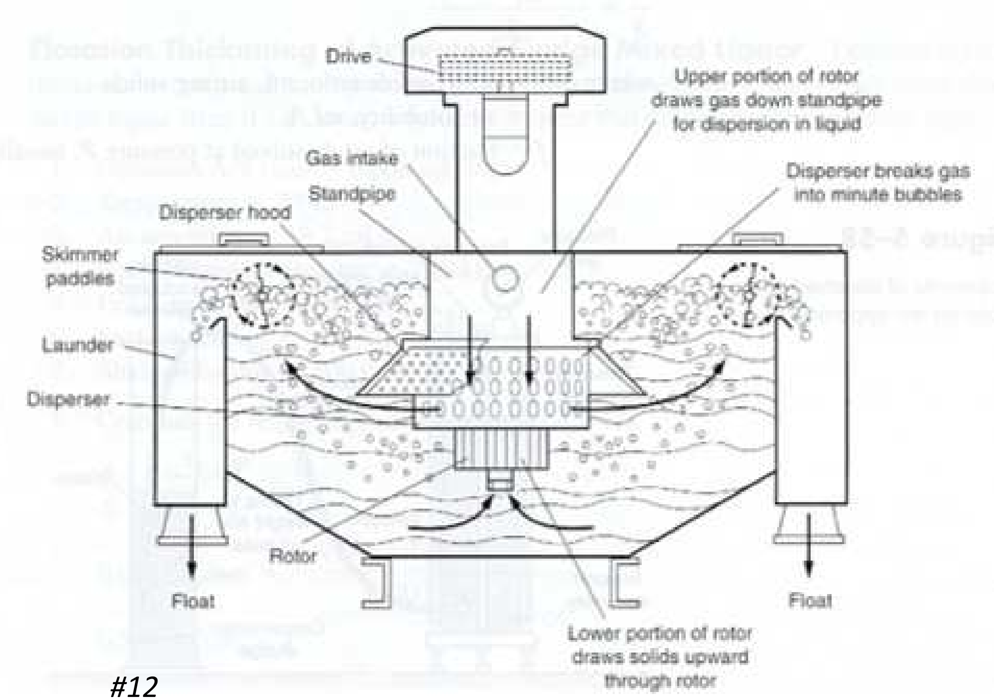


Figure 5–56

Schematic of dissolved-air flotation systems: (a) without recycle in which the entire flow is passed through the pressurizing tank and (b) with recycle in which only the recycle flow is pressurized. The pressurized flow is mixed with the influent before being released into the flotation tank.

Types of flotation unit processes

- **Dispersed-Air Flotation**
  – A revolving impeller forces water through disperser openings and creates a vacuum in the standpipe
  – The vacuum pulls air into the standpipe and mixes it with the water
  – Fine bubbles are created by a mixing force and by the movement of the fluid through a series of cells
  – Less frequently used – mainly used in industrial wastewater treatment



#12

Mixing

- Application of mixing in wastewater treatment
  - Continuous rapid mixing
    - Blending of chemicals with wastewater
    - Blending of miscible liquids
    - Addition of chemicals to sludge and biosolids
  - (Slower) Continuous mixing
    - Keeping the contents of a reactor or storage tanks in suspension (e.g., for biological treatment)
    - Flocculation (after adding coagulants - more common in drinking water treatment!)

The G value

- Velocity gradients and power requirement
  - Mixing can be viewed as a development of velocity gradients among fluid
  - "G value": average velocity gradient, a measure of mixing intensity

Camp and Stein (1943)

$$G = \sqrt{\frac{P}{\mu V}}$$

G = average velocity gradient (1/s)
P = power requirement (W)
μ = dynamic viscosity (N-s/m^2)
V = reactor volume (m^3)

⇨ The effectiveness of mixing is a function of power input per volume

⇨ Greater power requirement to achieve greater G with the same reactor volume;

Greater power requirement to achieve the same G with the larger reactor volume

Range of retention time and G value for mixing

- rapid mixing: G↑ with small τ
- gentle mixing (flocculation): G↓ with large τ

Process	Range of values	
	Retention time	G value, s^{-1}
Mixing		
Typical rapid mixing operations in wastewater treatment	5-30 s	500-1500
Rapid mixing for effective initial contact and dispersion of chemicals	<1 s	1500-6000
Rapid mixing of chemicals in contact filtrations processes	<1 s	2500-7500
Flocculation		
Typical flocculation processes used in wastewater treatment	30-60 min	50-100
Flocculation in direct filtration processes	2-10 min	25-150
Flocculation in contact filtration processes	2-5 min	25-200

Mixing

Q: Determine the theoretical power requirement to achieve a G value of 100/s in a tank with a volume of 2800 m^3. Assume that the water temperature is 15°C. What is the corresponding value when the water temperature is 5°C?

Dynamic viscosity values:

15°C: 1.139×10^{-3} N-s/m^2

5°C: 1.518×10^{-3} N-s/m^2

Mixing

$$G = \sqrt{\frac{P}{\mu V}}$$

⇨ $P = G^2 \mu V$

@ 15^{o}C: $P = (100/s)^2 \times (1.139 \times 10^{-3}\ N - s/m) \times (2800\ m^3) = 31900\ W$

$= 31.9\ kW$

@ 5^{o}C: $P = (100/s)^2 \times (1.518 \times 10^{-3}\ N - s/m) \times (2800\ m^3) = 42500\ W$

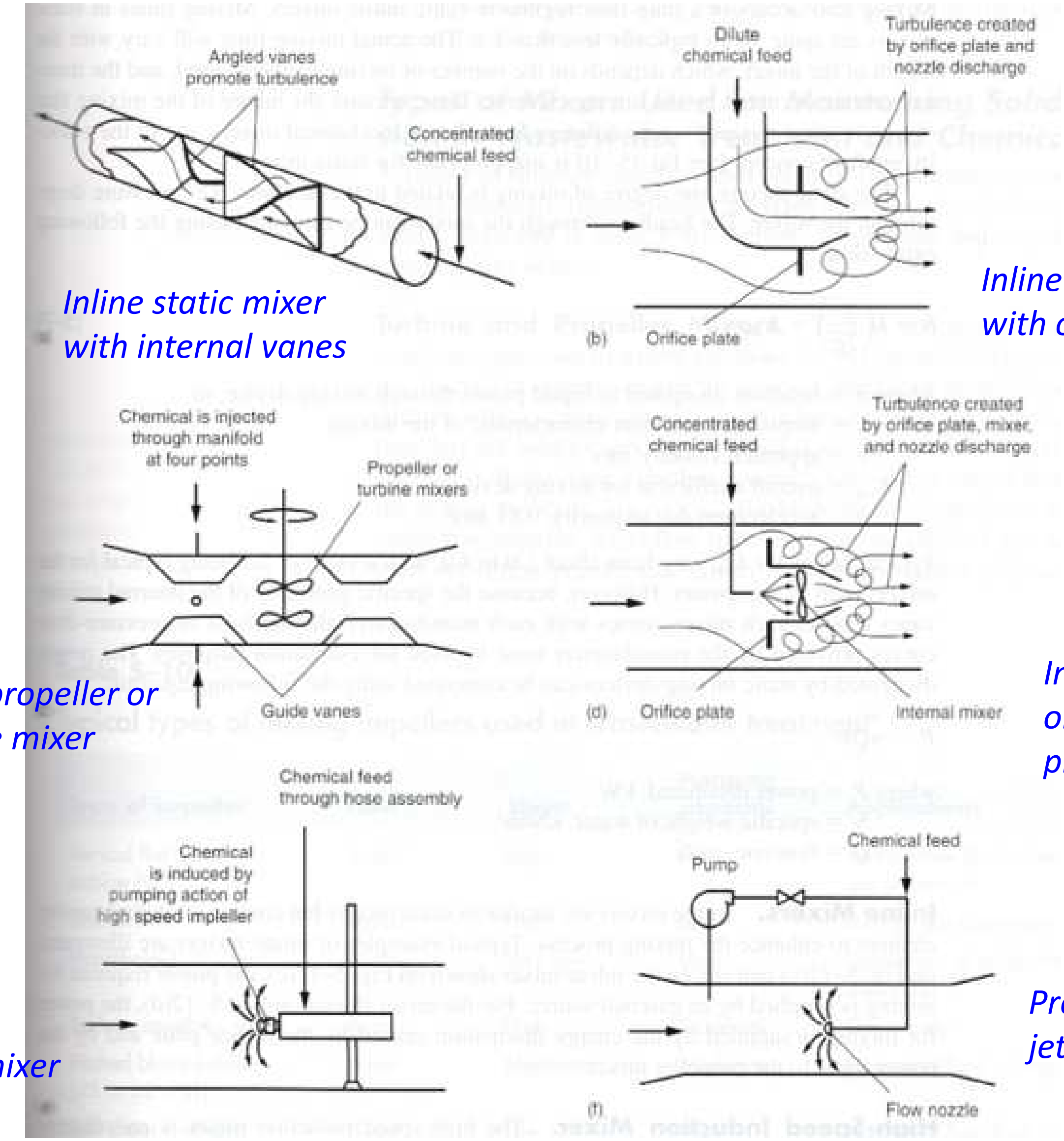
$= 42.5\ kW$

Results indicate that as temperature ↓, viscosity ↑, so more power input is required for the same intensity of mixing

Types of mixers (1)

Typical mixers used for rapid mixing of chemicals

#13



Inline static mixer with internal vanes

Inline static mixer with orifice

Inline propeller or turbine mixer

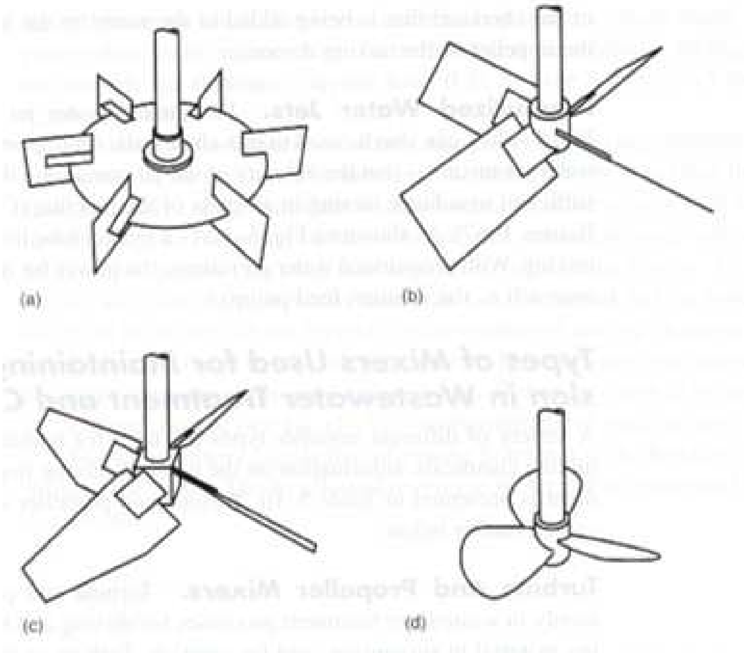
Inline mixer with orifice and internal propeller mixer

High-speed induction mixer

Pressurized water jet mixer

Types of mixers (2)

Mixers for maintaining solids in suspension and chemical blending in reactors: turbine and propeller mixers most common



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Types of mixers (3)

- Type of mixers used for bio
  - Pneumatic mixing
    - mixing is provided by inject
    - both mixing effect & oxyge
    - used for aeration tank of ar

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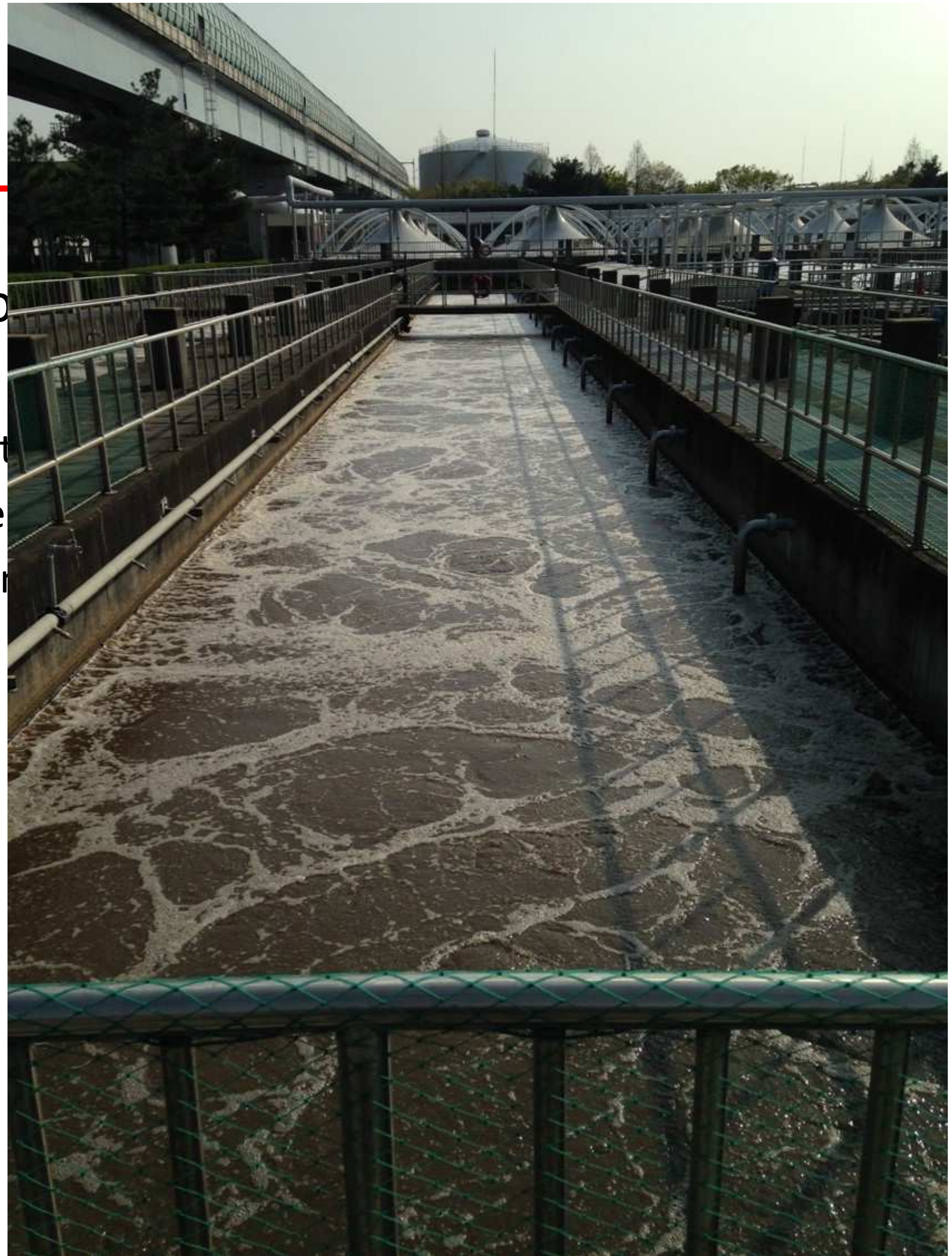
Ceramic disk diffuser

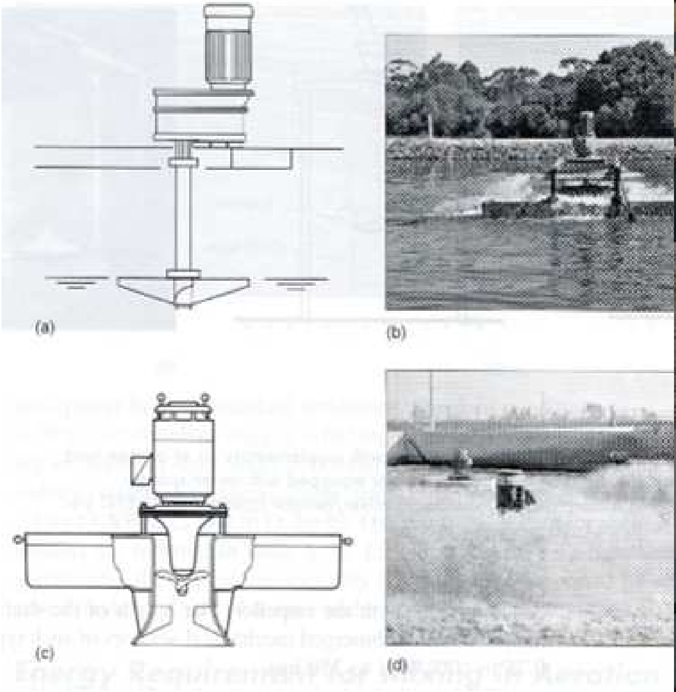


devices to an aeration tank

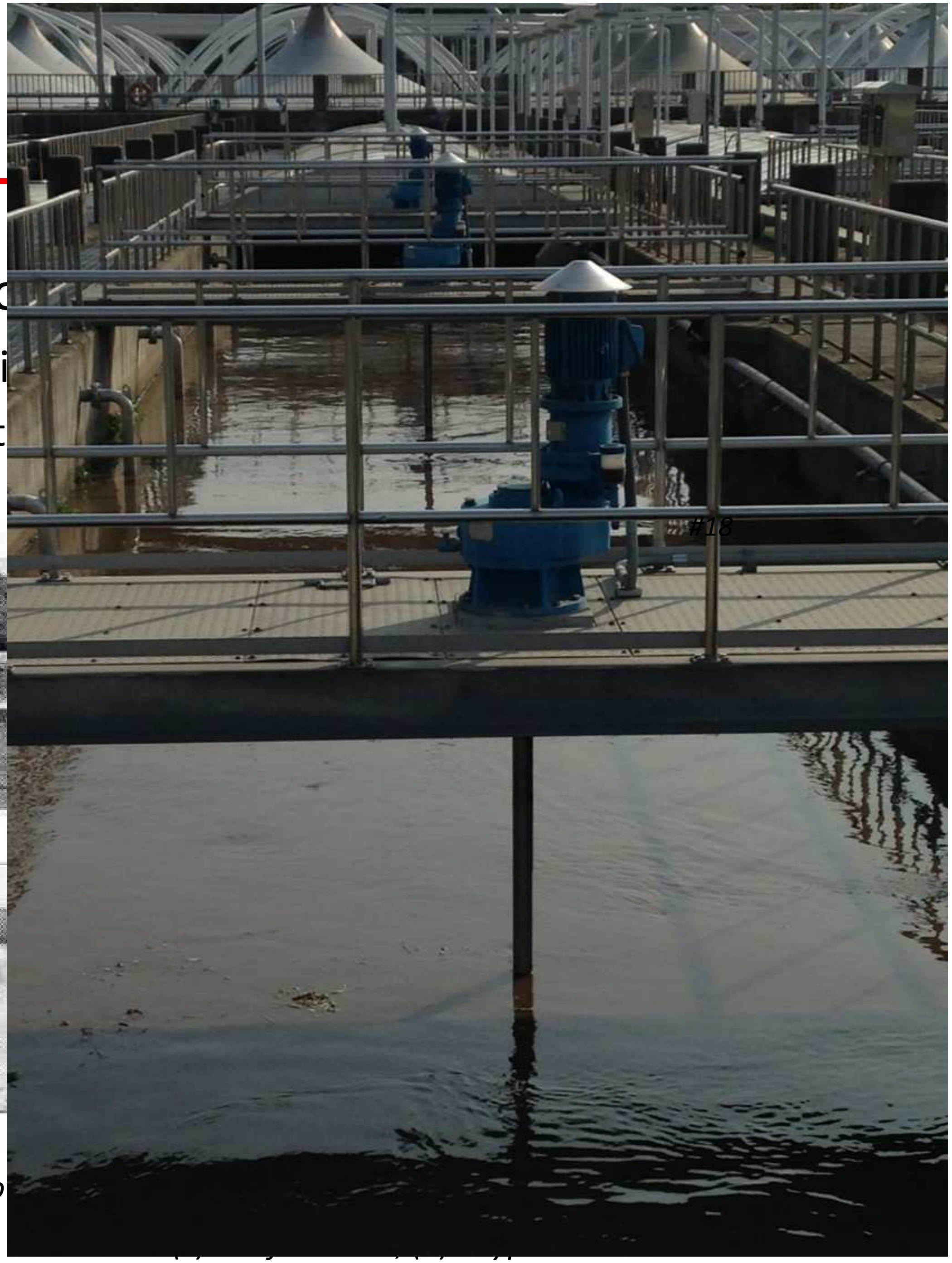
Types of mixers (4)

- Type of mixers used for bic
  - Mechanical aerators and mi
    - for anoxic/anaerobic react

#17



Surface mechanical aerators: (a), (b) – lo
speed; (c), (d) – high-speed



#18

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#1-#3) Metcalf & Eddy, Aecom (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th ed. McGraw-Hill, p. 1133, 1130, 1132.

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