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>
• Headloss buildup and effluent quality

- The shorter of the $t_{\text{headloss}}$ and $t_{\text{breakthrough}}$ will be the time for backwash cycle
- Optimized design: design the filter such that $t_{\text{headloss}} \approx t_{\text{breakthrough}}$
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

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

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**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 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
  - **Use a more concentrated solution** (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 CO₂ 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: \( C_s \to 0 \)

- 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, ...)