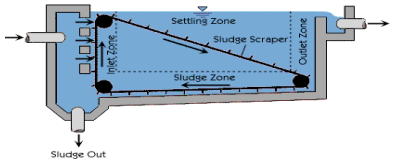
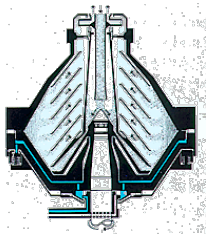
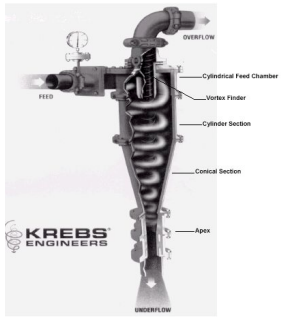


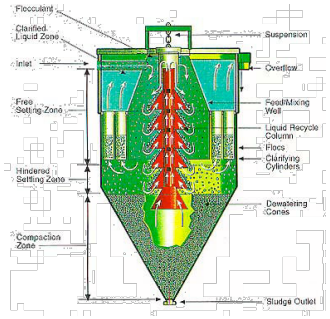




Solid-Liquid Separation

Murat Mirata

November 2008



Selection depends on…

- Physical & chemical characteristics of both solids & liquid;
- Desired characteristics of products;
- Nature of the process;
- Resource availability
  - Money
  - Time
  - Space
  - Personnel
  - Knowledge

Mechanism of Removal

Can include any combination of the following

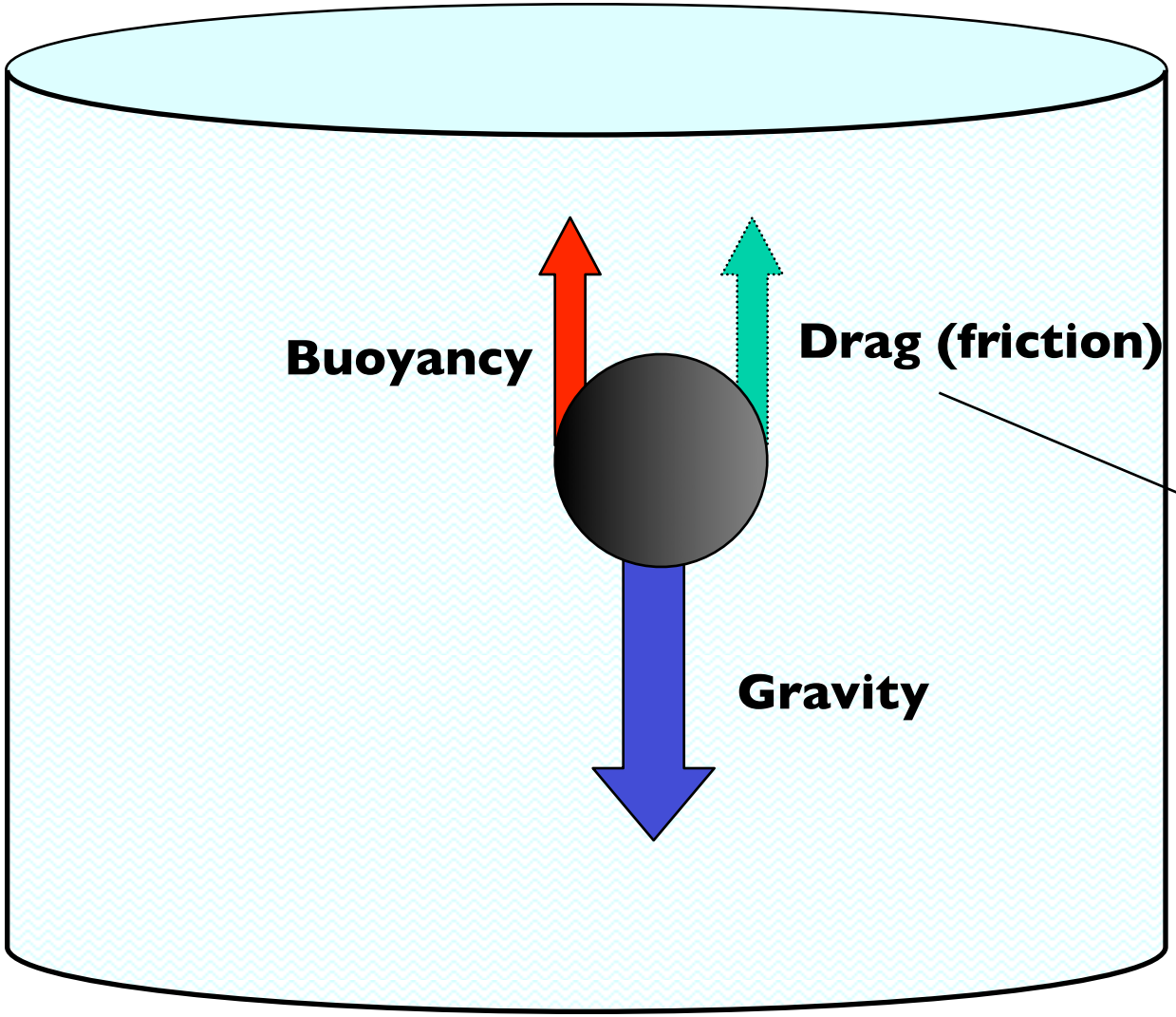
- Mechanical
- Chemical
- Biological
- Thermal
- Electrical

- **Gravity**
- **Centrifugal Forces**
- **Pressure difference**
- **Size difference**
- **Adsorption (stickyness)**

What sorts of solids?

- Suspended settleable solids
- Suspended colloidal particles (D < 1 μm)
- Dissolved solids(D < a few nanometers)

Forces on a Particle

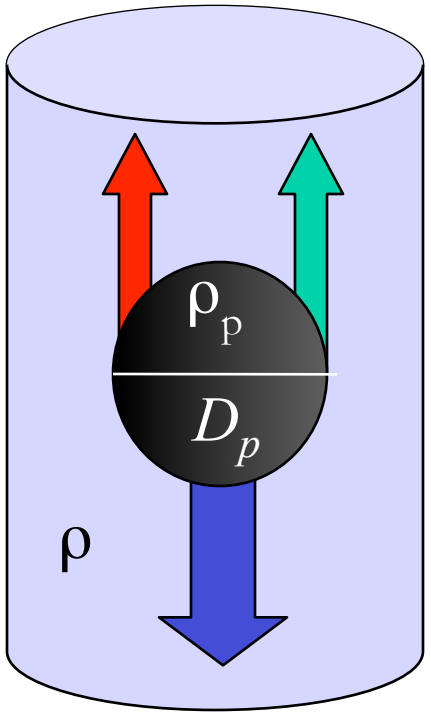


Acts always in the opposite direction of the movement

Settling Velocity

$$u = \frac{D_p^2 \times (\rho_p - \rho) \times g}{18 \times \eta}$$

u = settling velocity of particle (m/s)
D_p = diameter or particle (m)
ρ_p = density of particle (kg/m^3)
ρ = density of fluid (kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
η = dynamic viscosity of fluid (k/m s)



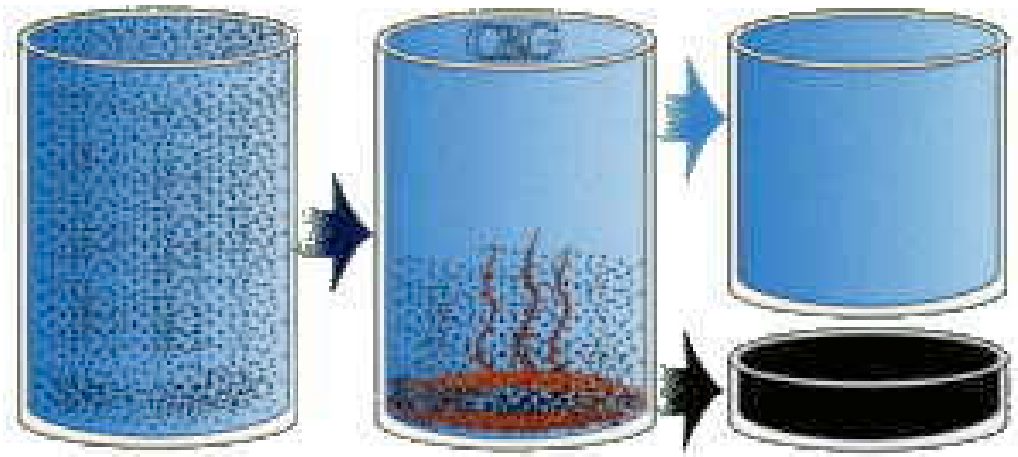
Terminal settling velocities

Part. Diam (μm)	Terminal Vel. (mm/sec)	Characteristic Description
1000	100	Coarse sand
500	60	Coarse sand
200	30	Coarse/fine sand
100	6	Fine sand
50	1.5	Fine sand
10	0.06	Silt
5	1.5×10^{-3}	Silt
2	2.2×10^{-4}	Silt/clay
1	6.0×10^{-5}	Clay

7

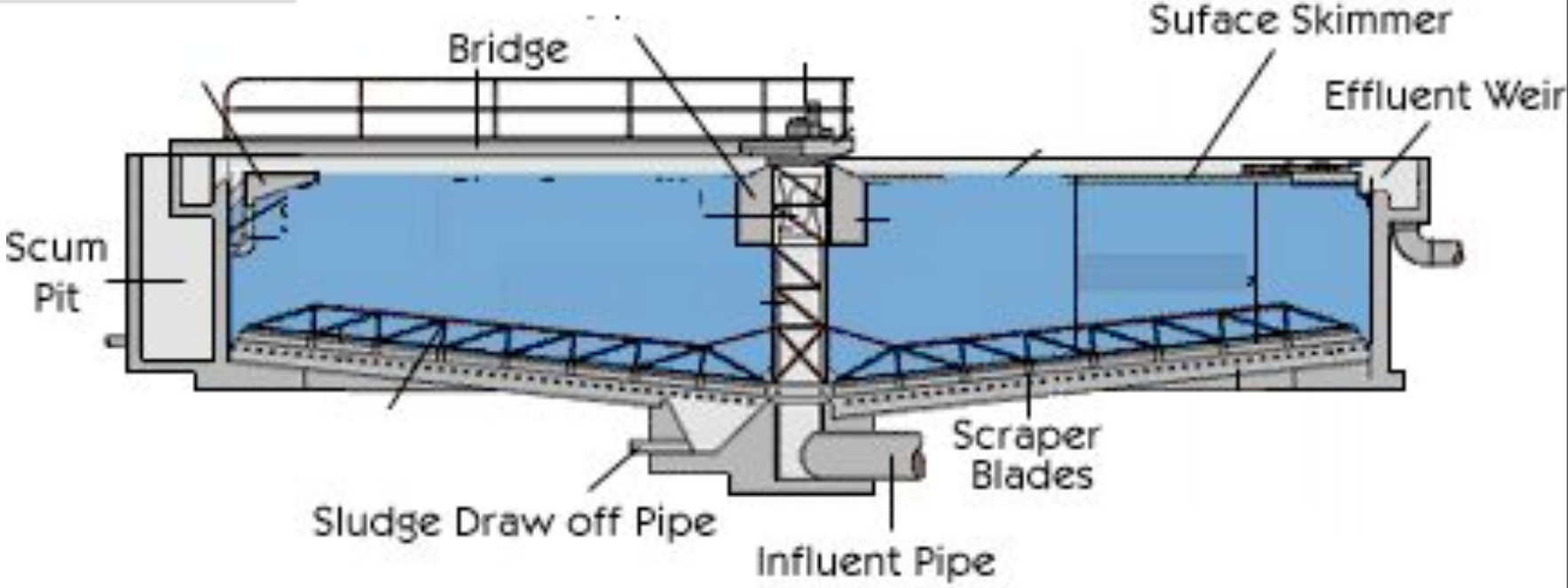
(Hocking, 19

Sedimentation



Types of Clarifiers

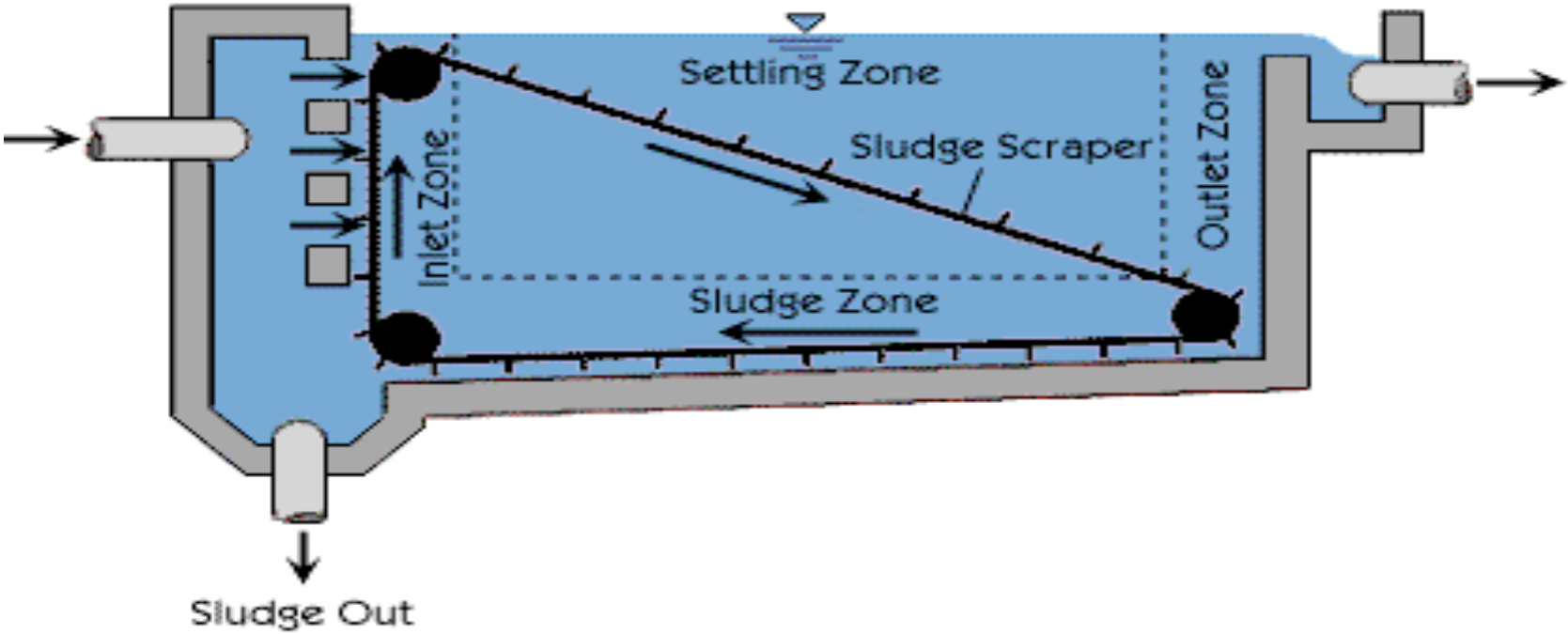
CIRCULAR



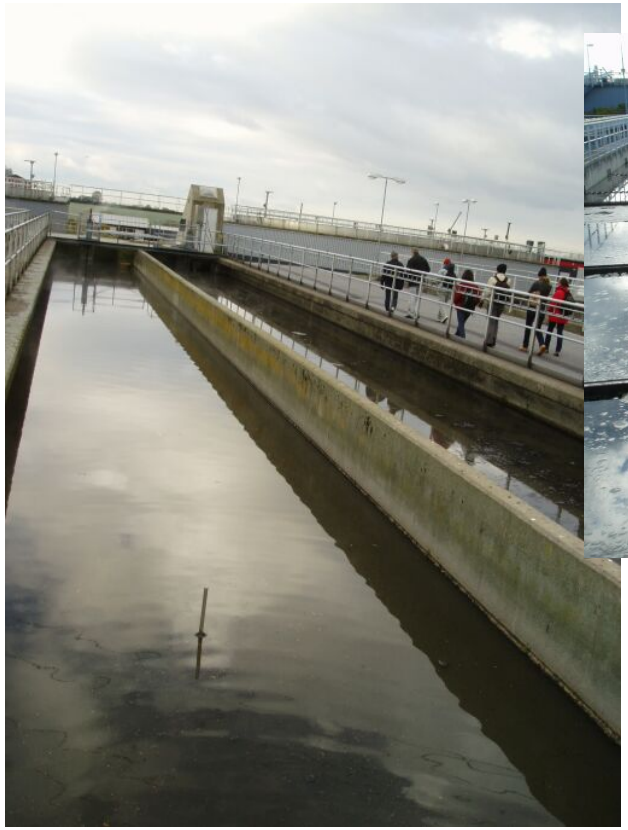
Circular tanks

Types of Clarifiers

RECTANGULAR

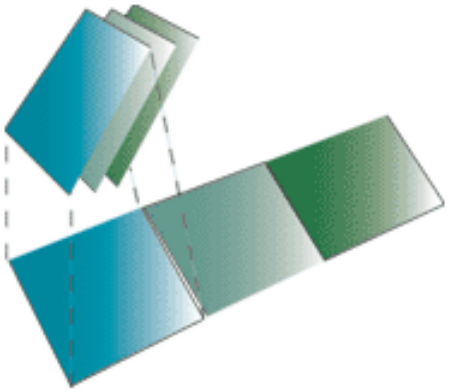


Rectangular sedimentation



Increased area - Lamella Separators

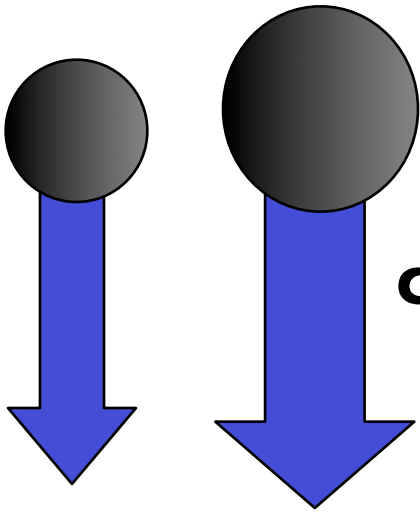
- Increased sedimentation area;
- Considerable reduction in size for the same efficiency;
- Costly;



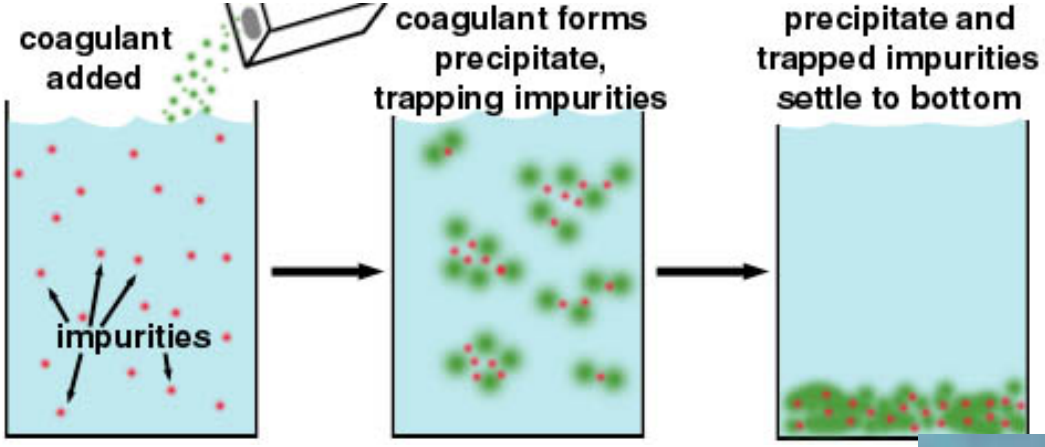
Chemical treatment

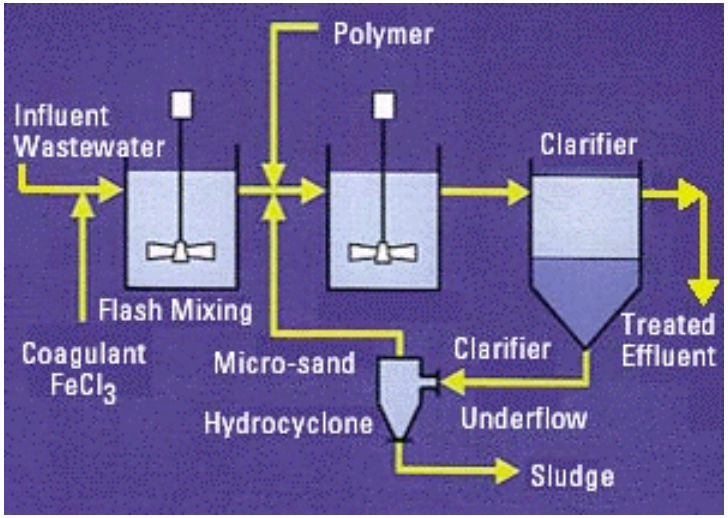
- Not a separation step itself;
- Bring smaller particles together to form bigger ones
  - Coagulants (alum, ferric sulfide, etc.)
  - Flocculants (electrolyte)
  - Ph adjustment

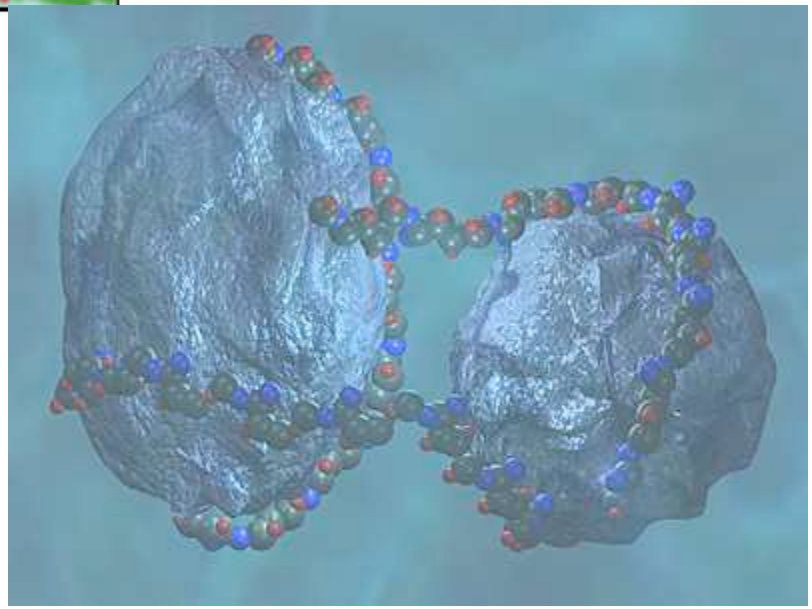
- Extra chemicals (pollutants) added to make it cleaner.
  - Costly
  - Excessive sludge
- Widely applied, e.g.:
  - Water treatment
  - Removal of dissovled chemicals
  - Removal of color from wastewaters
  - Etc.



Coagulation Mechanism

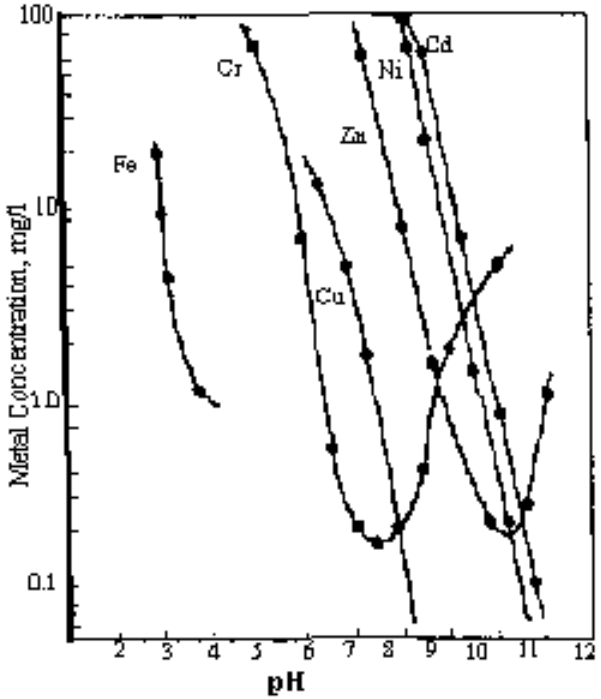






Chemical Precipitation

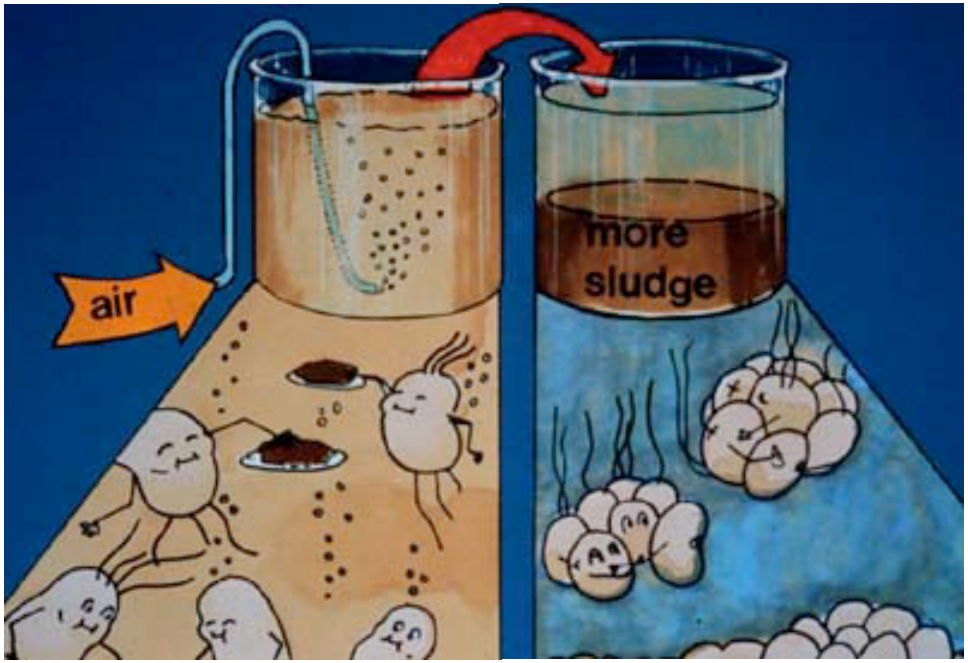
- Adjust the pH to form crystals



- Completion with clarifier or filters

Biological Processes

- Dissolved solids are broken down and assimilated (eaten) by bacteria;
- New bacteria formed is big enough to settle & removed in a clarifier.

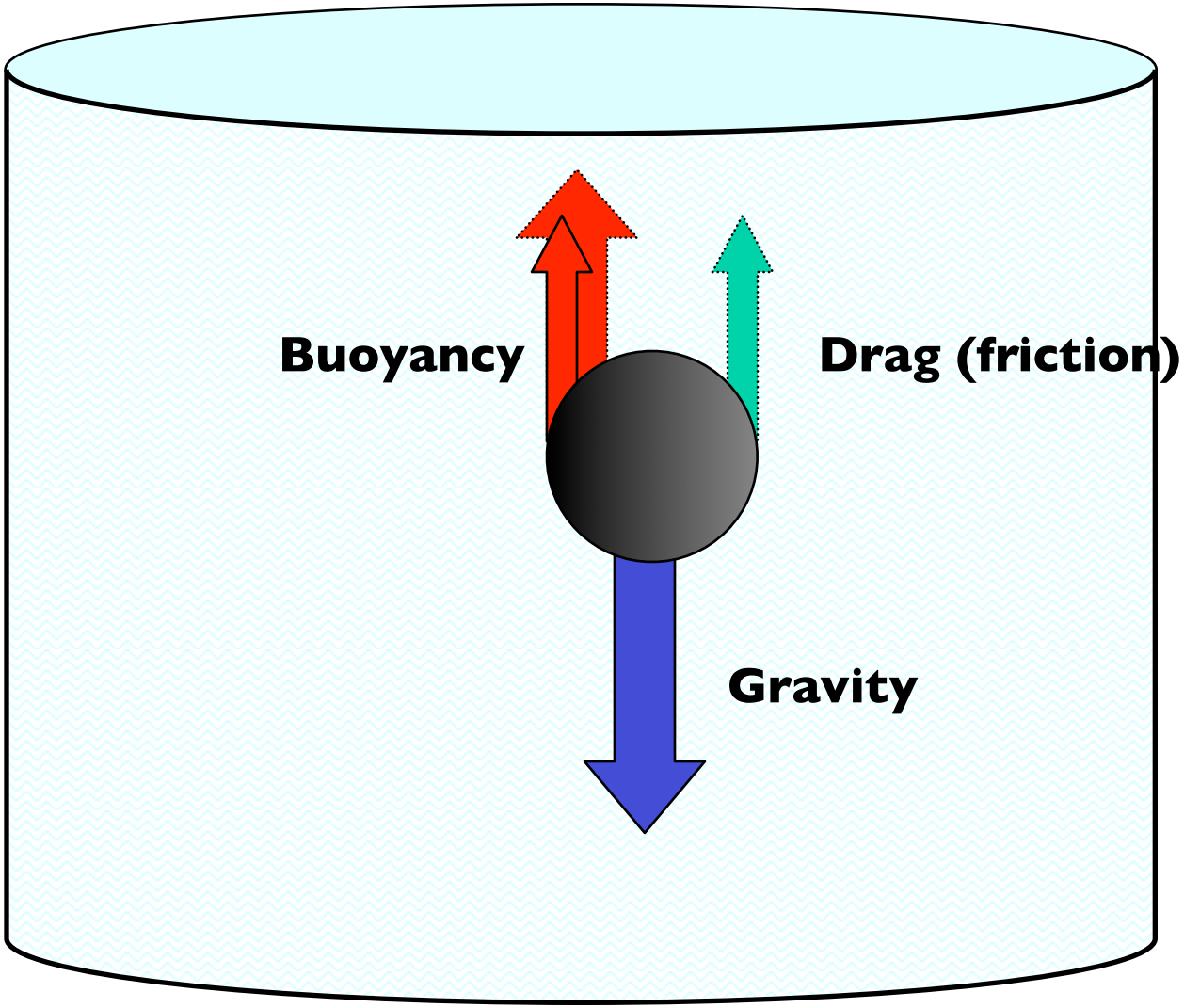


Biological processes

Be Aware

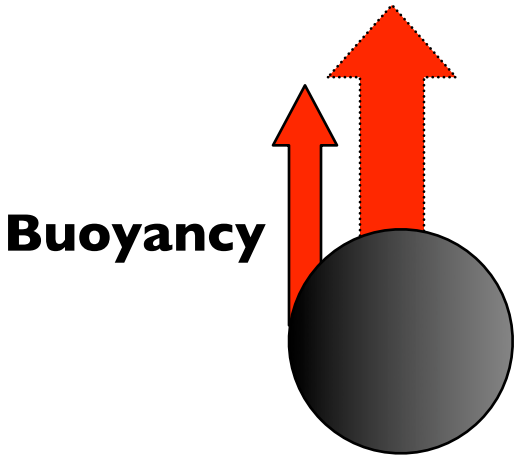
- Increasing the particle size is not a separation itself
- Needs to be followed by an appropriate application - e.g. sedimentation, filtration

Forces on a Particle

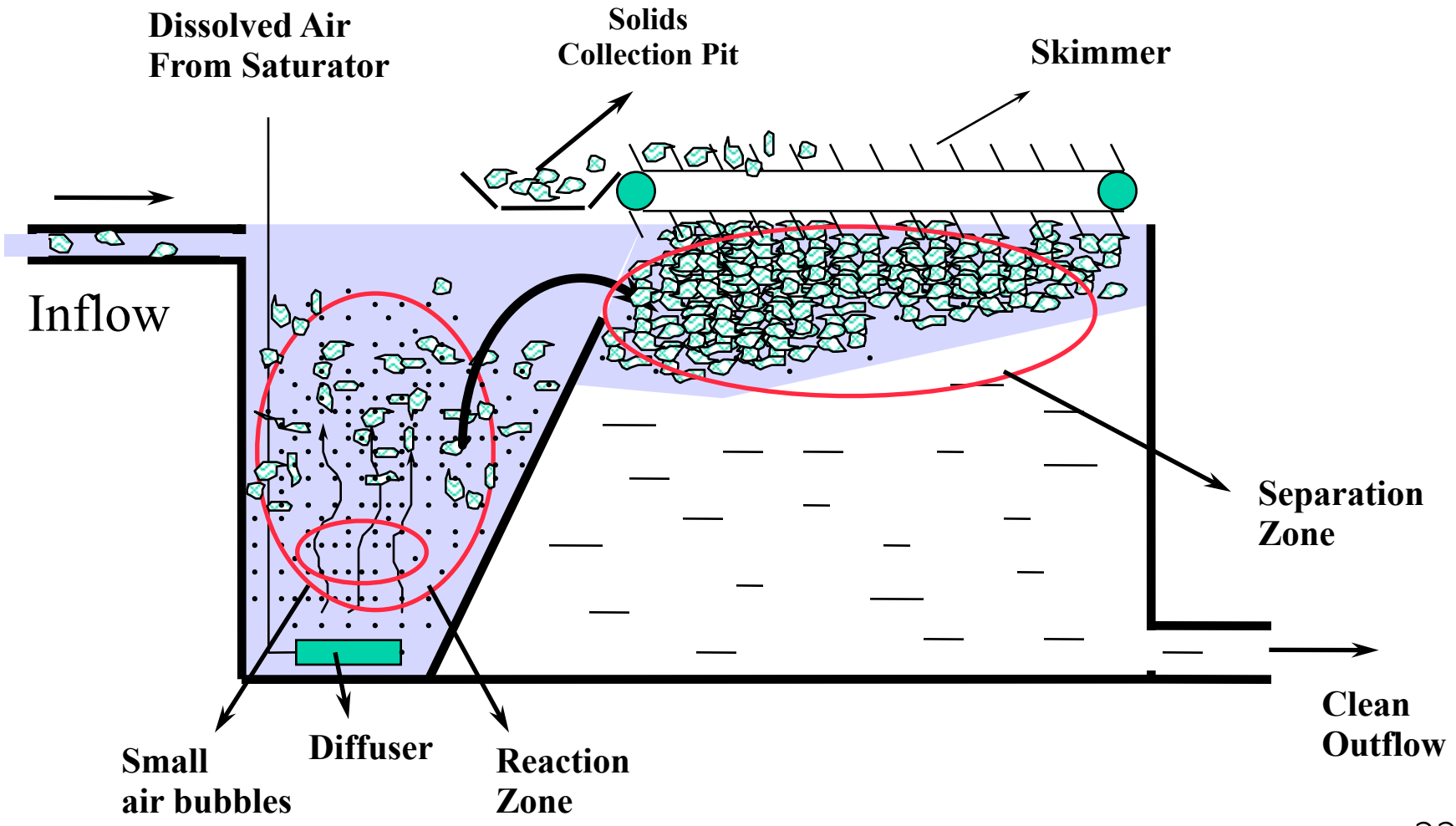


Floatation

- BUOYANCY: Main Driving Force
- Fine gas bubbles adhere to particles and bring them to liquid surface;



Floatation

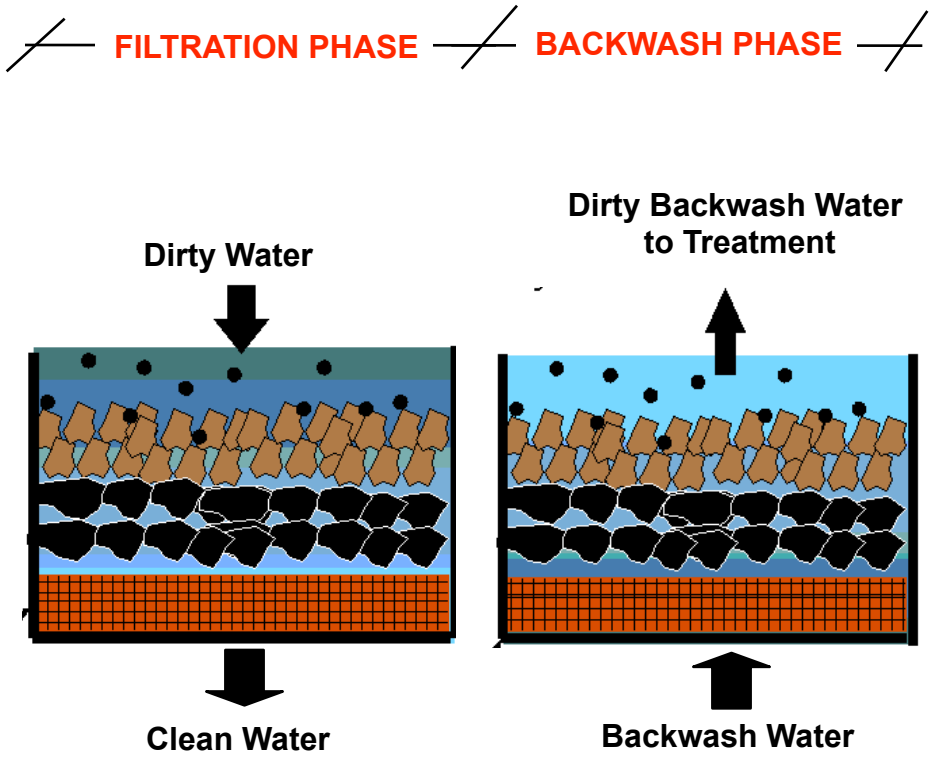

Dissolved Air
From Saturator
Solids
Collection Pit
Skimmer
Inflow
Separation
Zone
Clean
Outflow
Small
air bubbles
Diffuser
Reaction
Zone

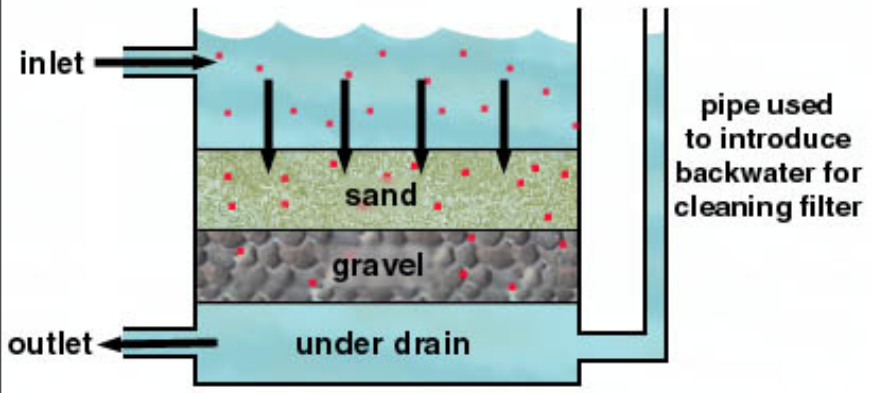
Dissolved Air Floatation

- Separation of oils (food processing, refineries, steel works, airports, etc.)
- Minerals processing
- Sludge thickening
- Separation and recovery of fibers from paper mill effluents
- Separation of metallic hydroxides
- Water & wastewater treatment

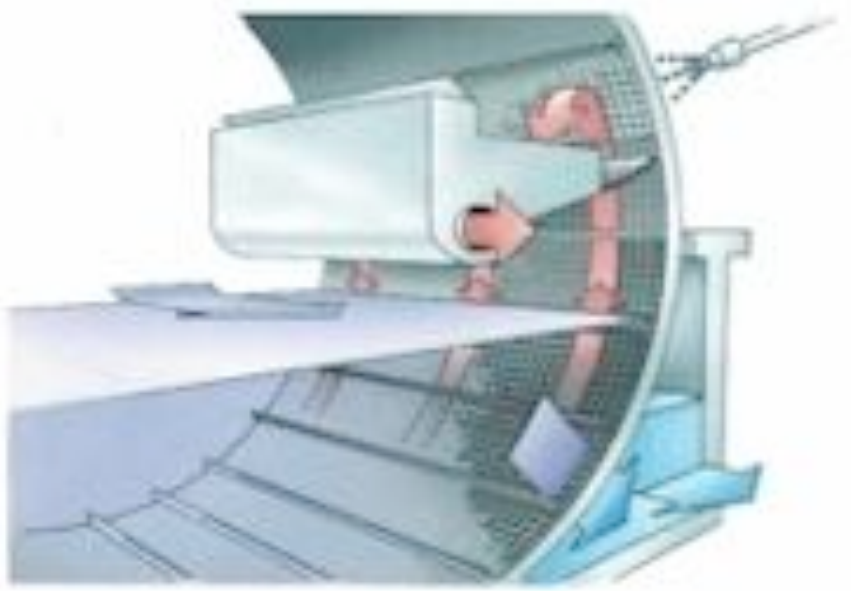
Filtration - Batch Operation

- Gravitational sand filters

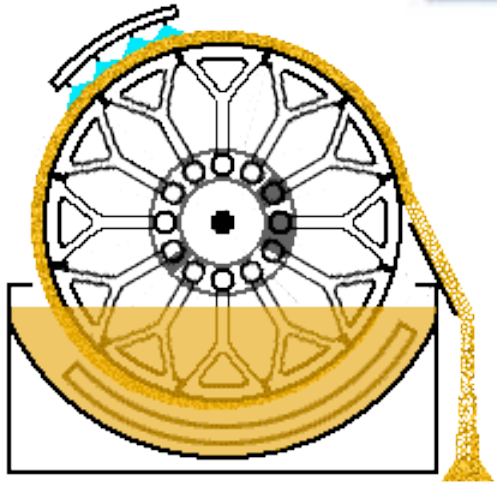




Continuous operations

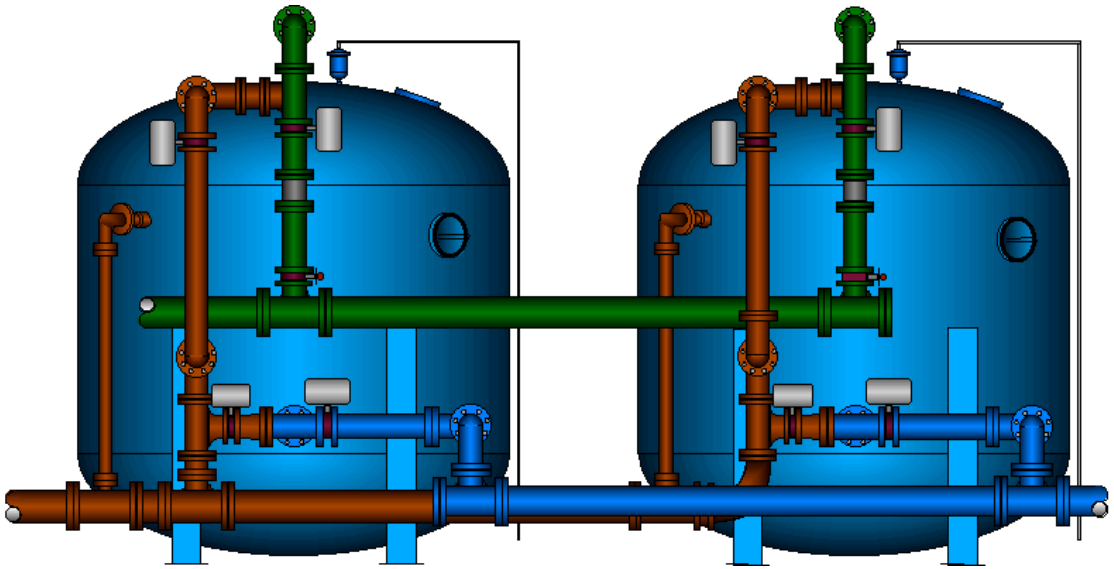


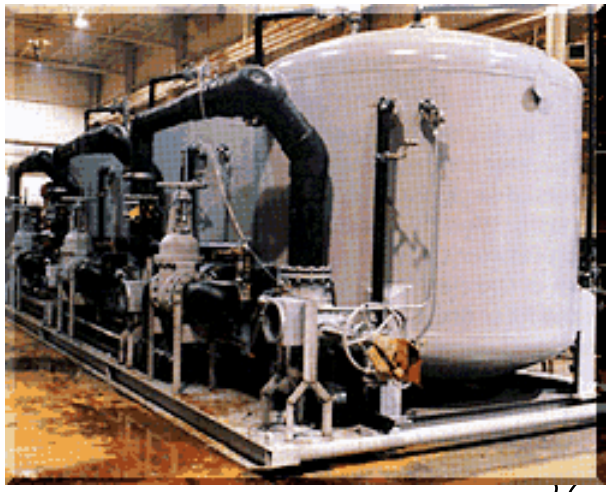
Drum Filter



Filtration

- Increased Pressure difference

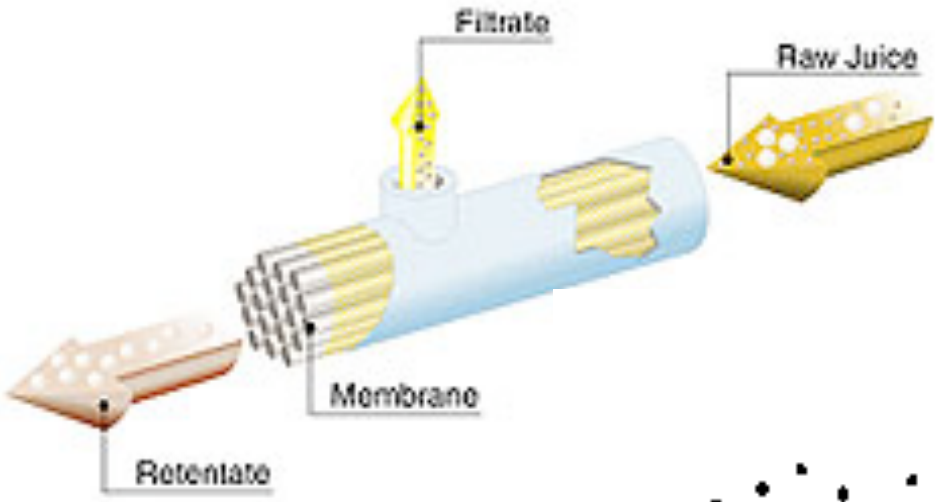


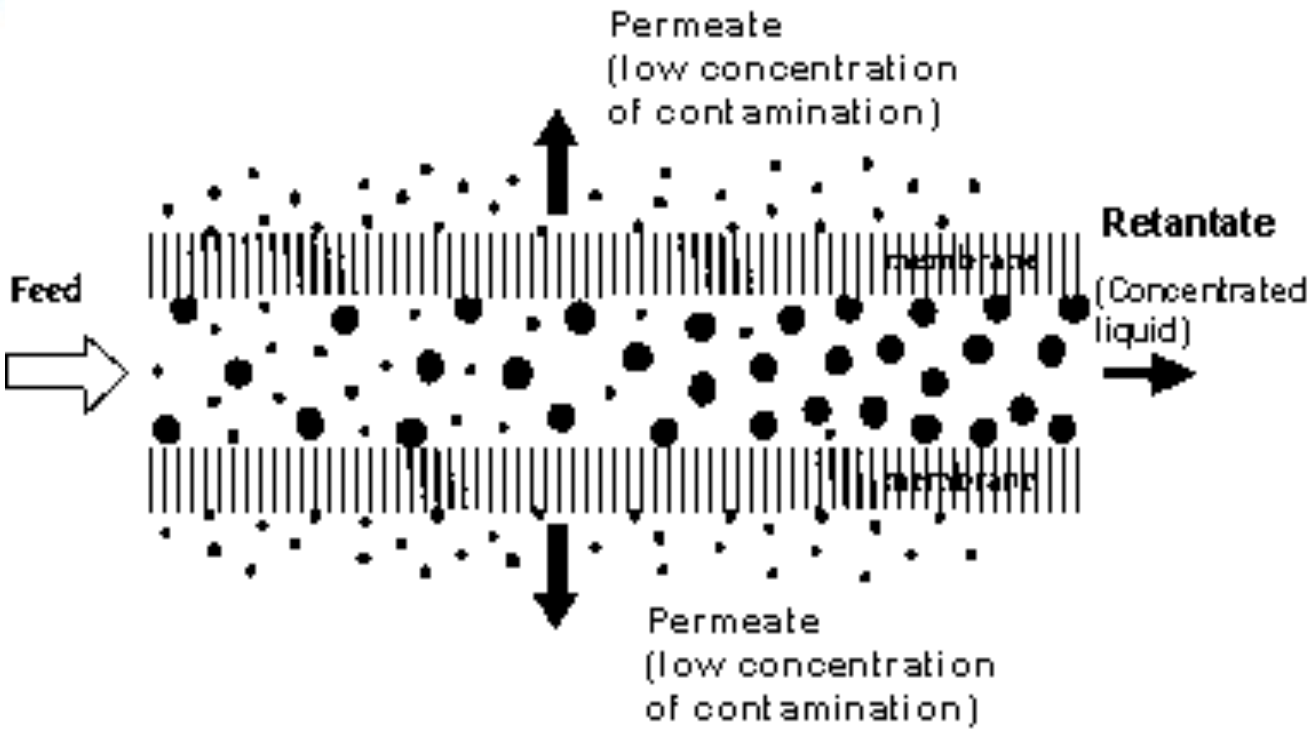


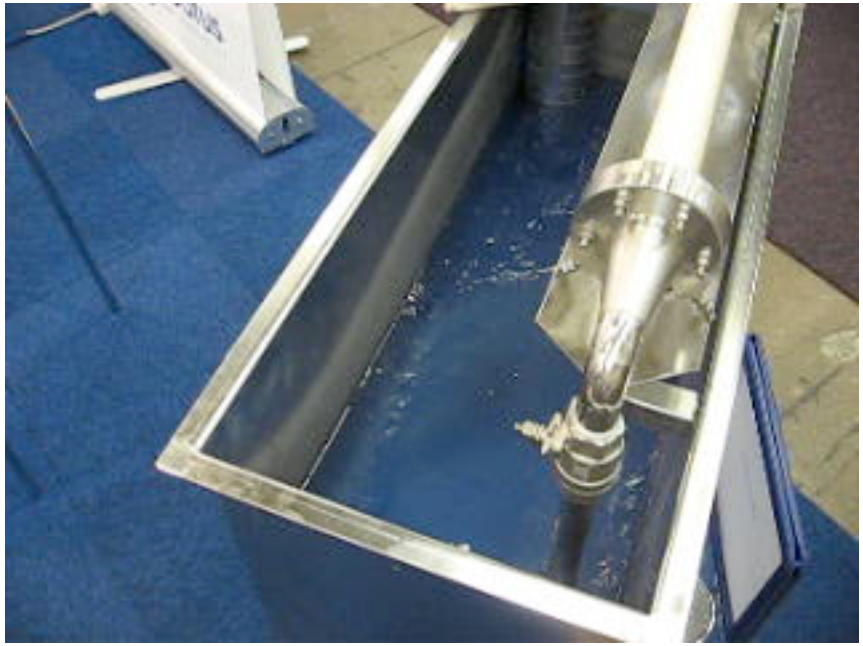
Membrane Technology

- A special type of continuous filtration technique using a semipermeable, selective barrier (membrane);
- Can separate particles on molecule/ion level;
- Pressure / Concentration / Electric potential as main driving forces;
- Membranes take different names depending on size of the molecules their ability to separate

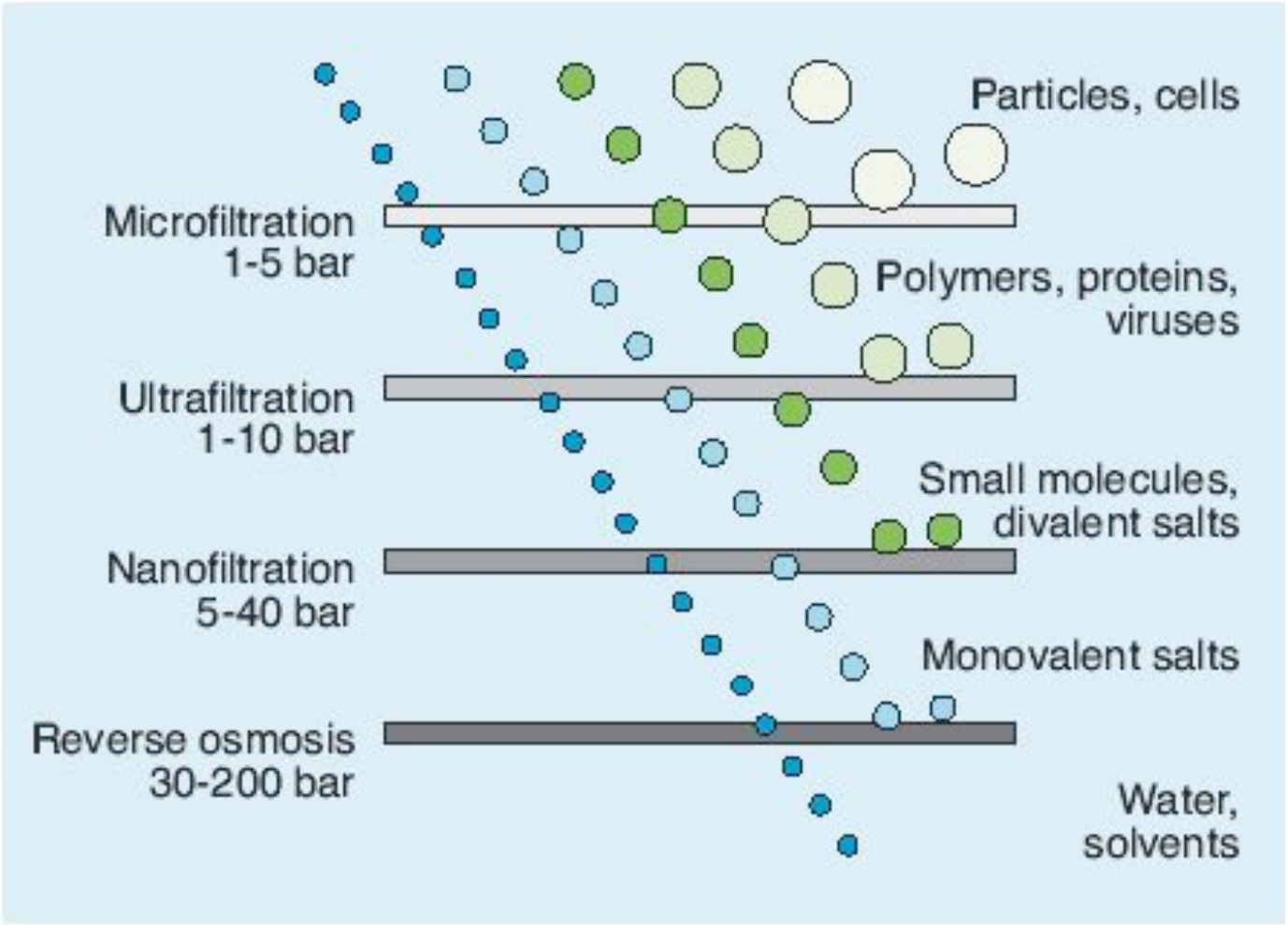
Membrane principle



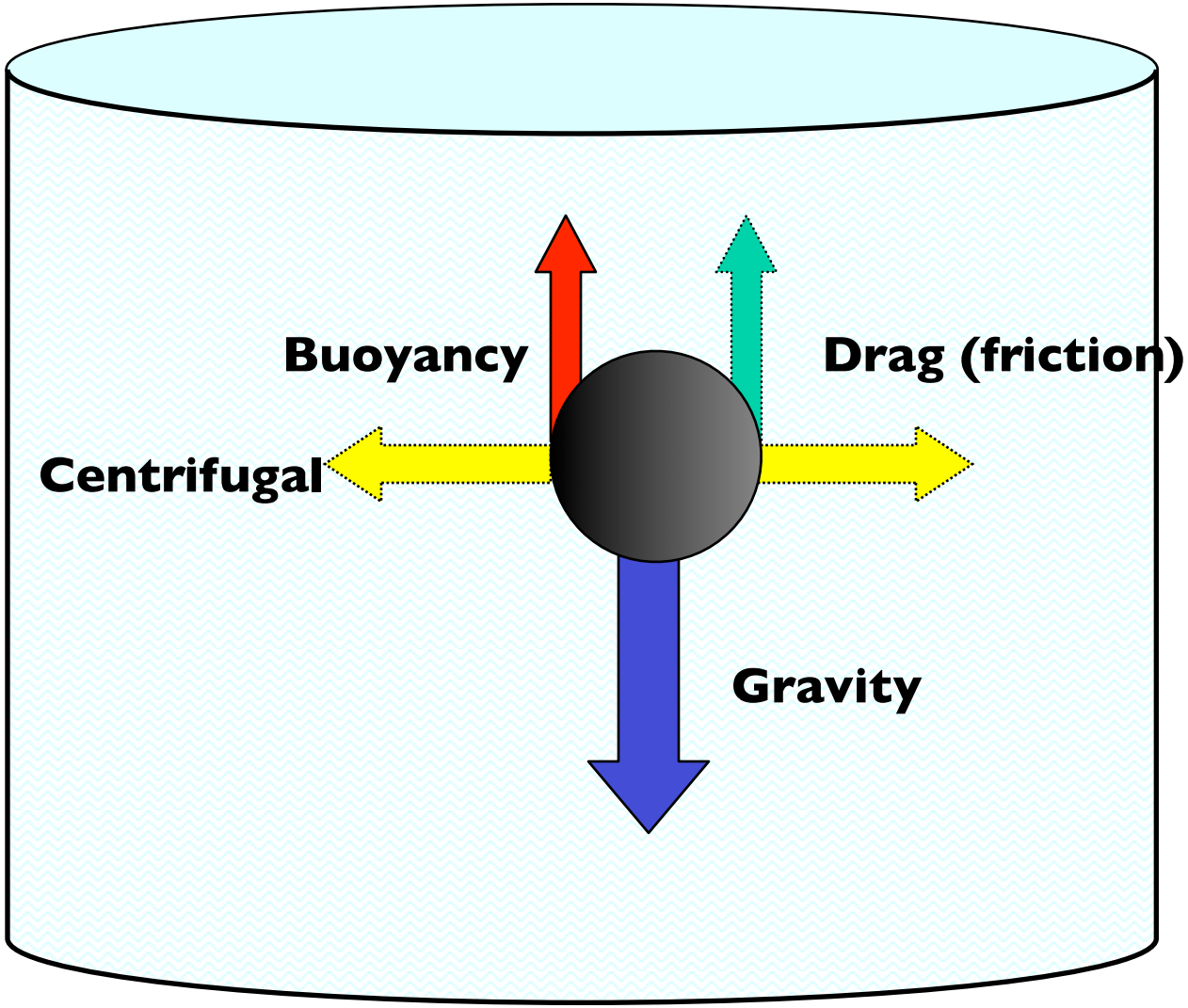




Particles removed



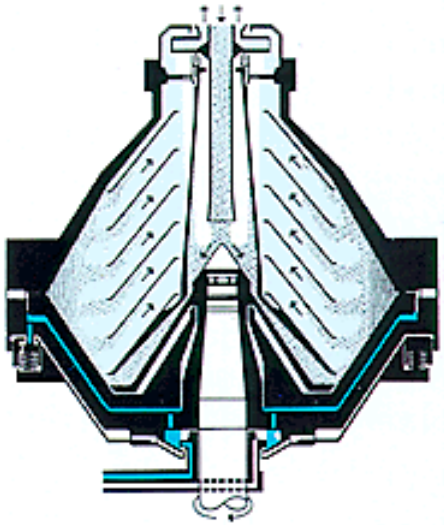
Forces on a Particle

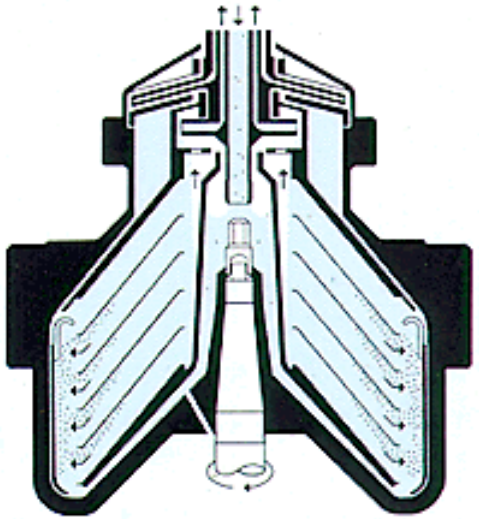


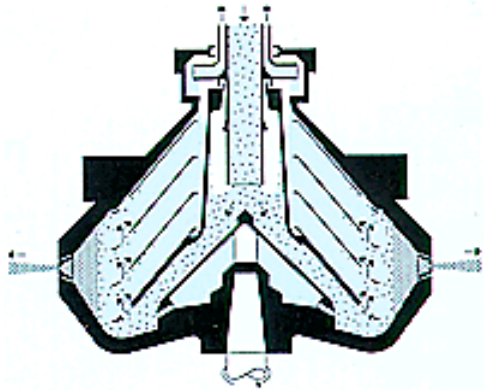
Centrifugation

- Centrifugal forces
- Sedimentation centrifuges;
  - Clear Liquid Required.
- Filter Centrifuges;
  - Pure, dryer solid.
- Very effective, compact equipment
- Can have large capital and operating expenses

Different Designs



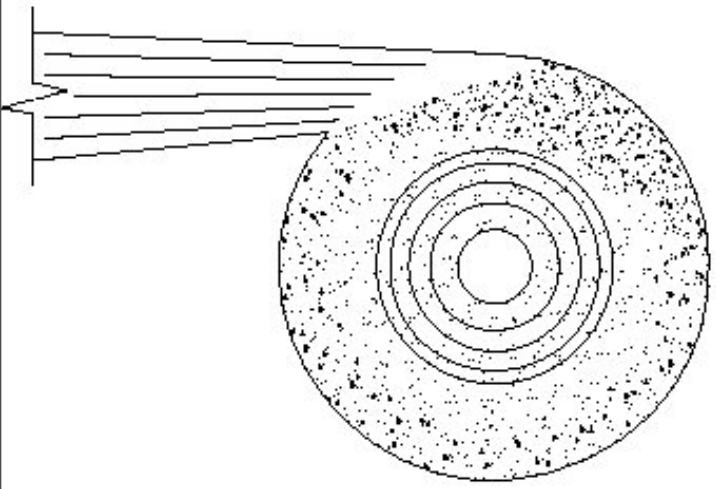


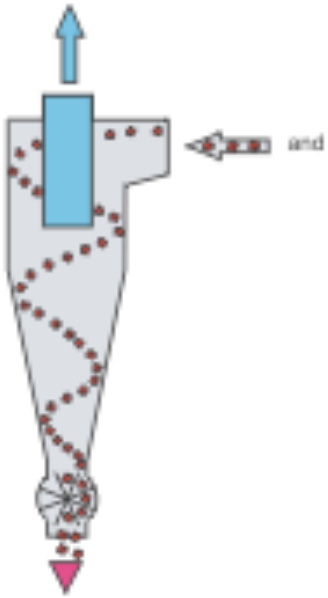


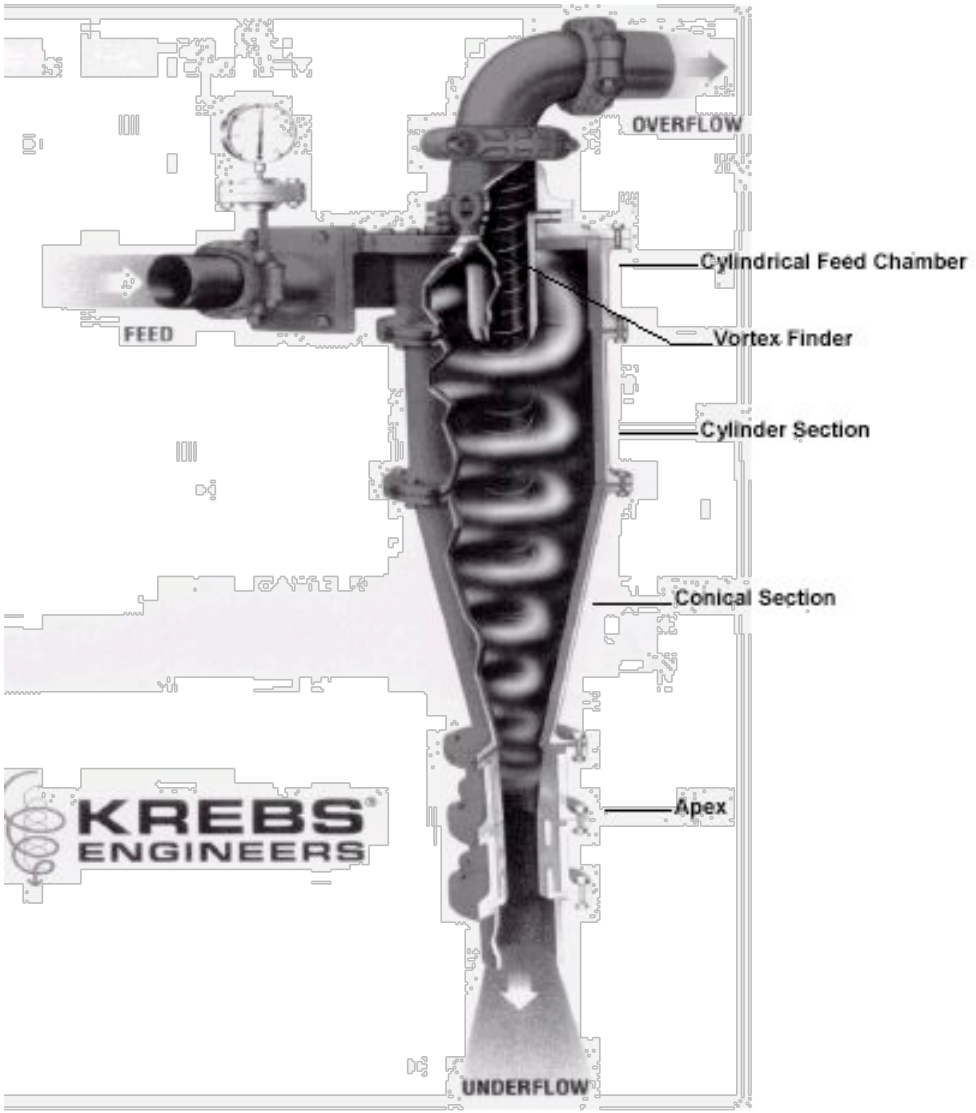
Cyclones

- Centrifugal forces created by the momentum of moving liquid;
  - Direction of movement changed through entry to cyclone;
- No moving parts, thus cheap;
- Effective;
- A given cyclone can only remove particles in a given size range – lack of flexibility;

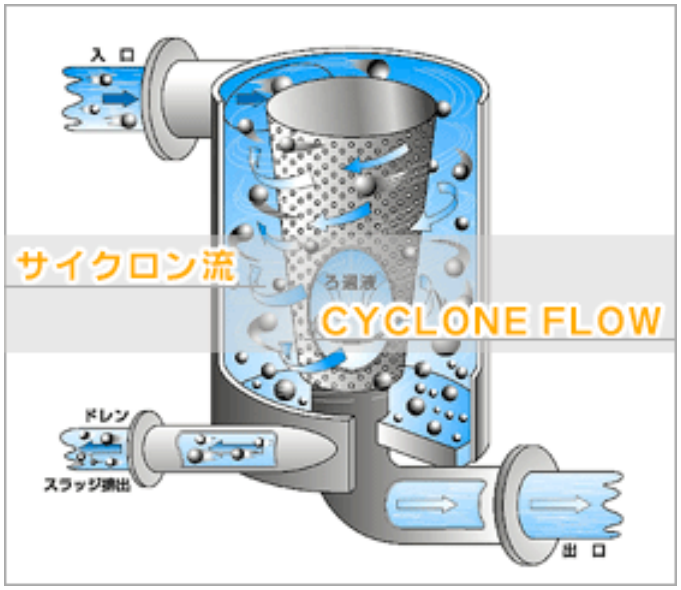
Cyclones






OVERFLOW
FEED
Cylindrical Feed Chamber
Vortex Finder
Cylinder Section
Conical Section
Apex
KREBS
ENGINEERS
UNDERFLOW

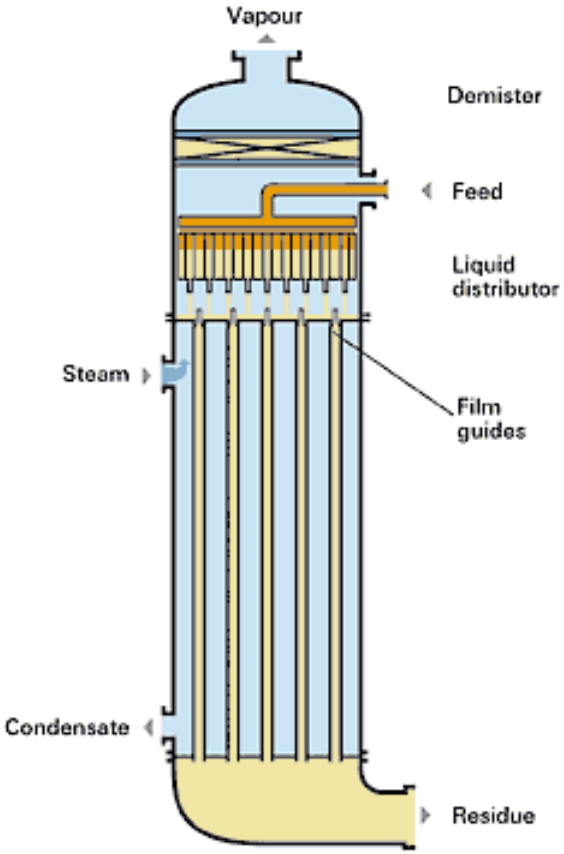
Cyclones



Forces and Residence Times

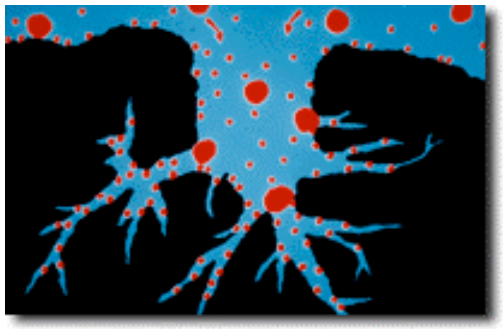
Technique	Relative Force	Typical Residence Time
Sedimentation	1	1 –2 hrs.
Floatation	1	20 –60 mins.
Centrifuge	1000 – 18000	10 –30 secs.
Cyclone	800 – 50 000	0,5 secs.

One type of evaporator



Carbon Adsorption

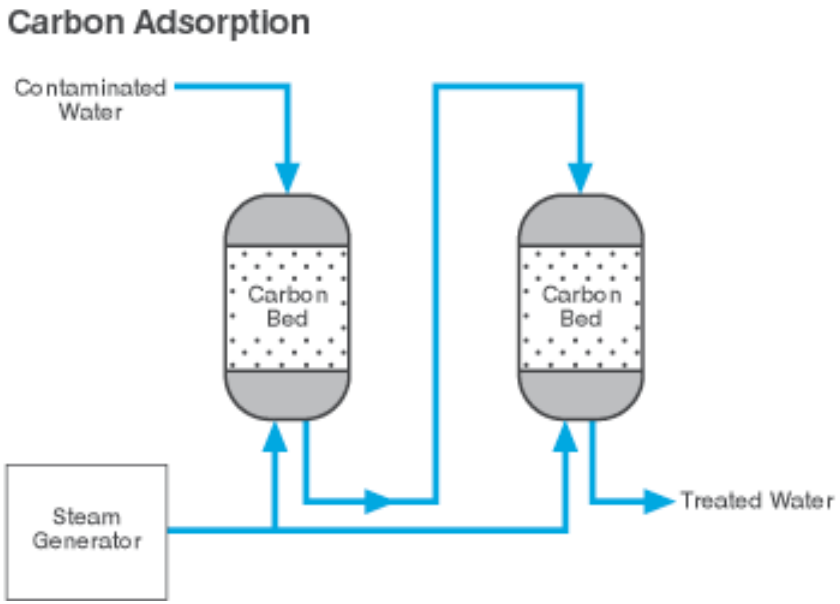
- Mechanism: Preference of solids to get attached to a solid surface;
- Large variety of compounds can be removed
  - Different sorts of organics
  - Heavy metals
  - Mineral oils



- Surface area & characteristics is important
- Operation in two cycles
  - Adsorption
  - Desorption

Highly effective but Costly

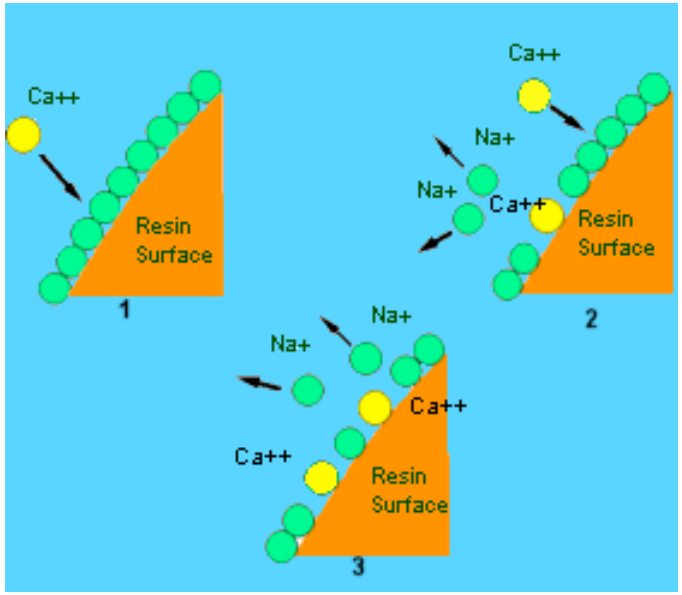
Operating mechanism



Ion exchange

- Mechanism: Chemical bonds between ions and special packing material.
- Positively and negatively charged ions are selectively get attached to special resins, displacing H^+ and OH^- ions, respectively;
- Operation in two cycles:
  - Removal of ions
  - Regeneration of resin

Ion exchange



Ion Exchange