Solid-Liquid Separation in Water Treatment

Settling and Flotation

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Introduction

The need to clarify water -

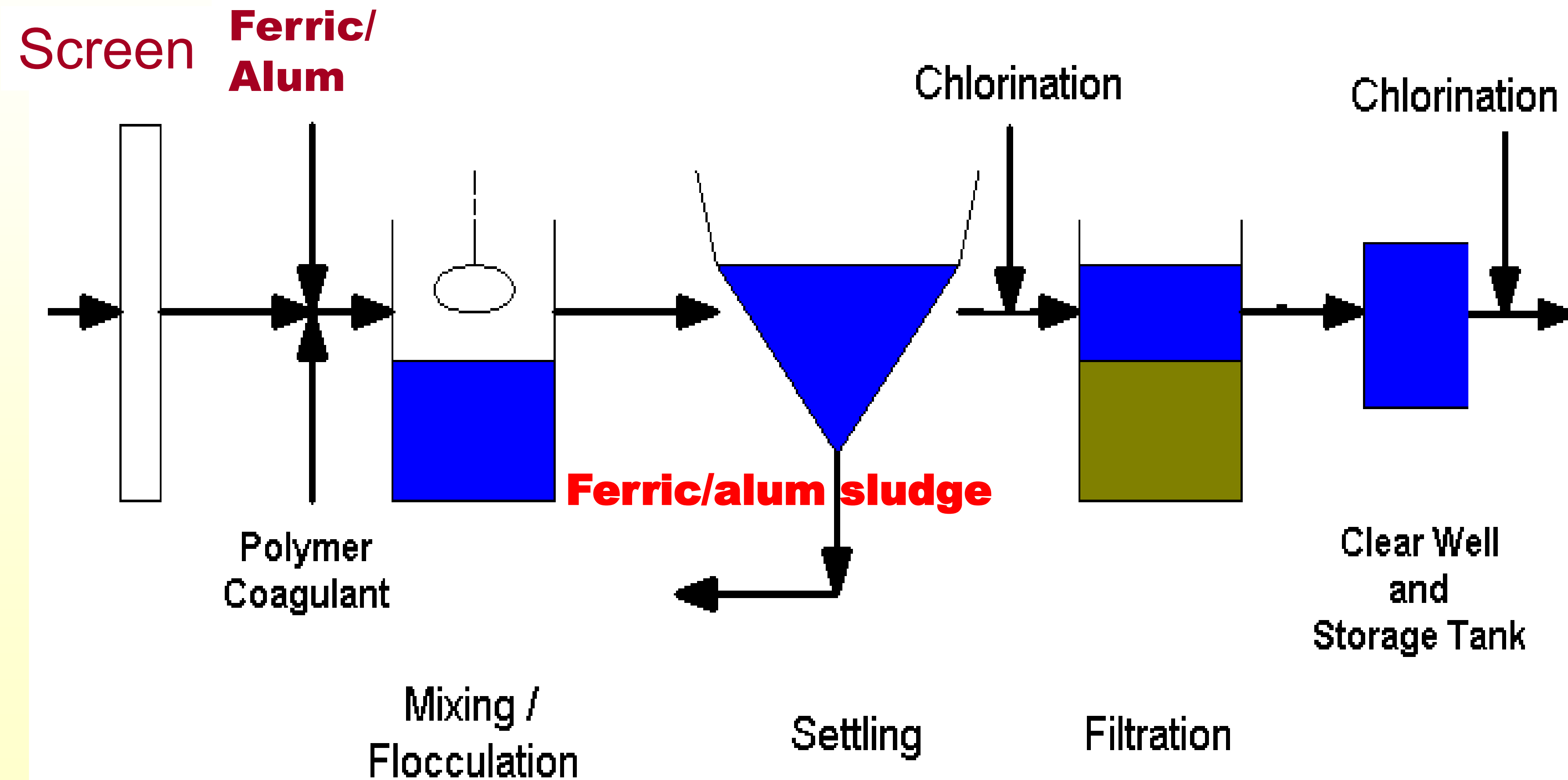
Aesthetic and health reasons

Technologies available

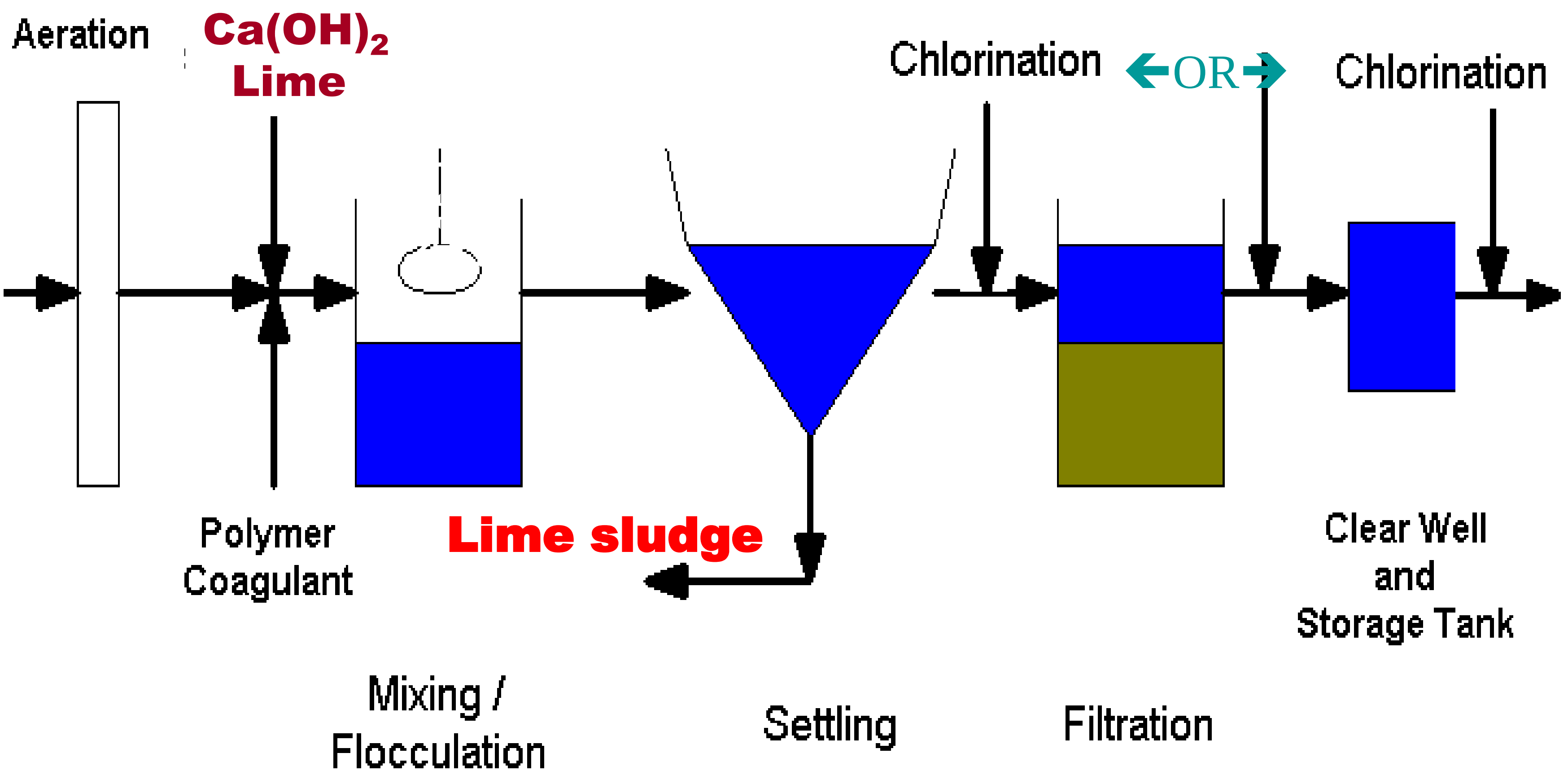
Topics of Discussion

- Separation by settling
- Separation by flotation
- Direct filtration
- Softening

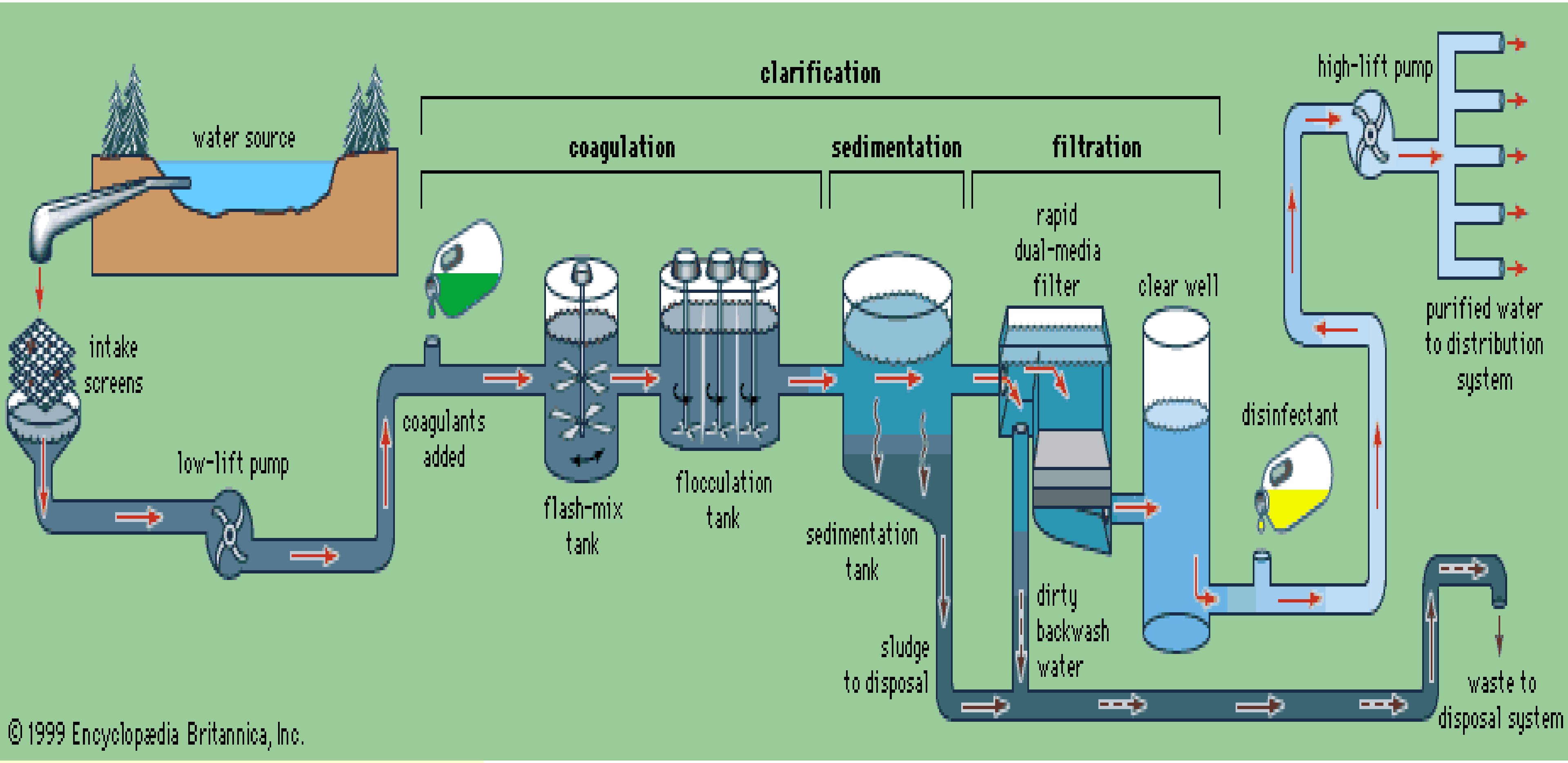
Typical surface water treatment process



Typical water treatment process with lime softening

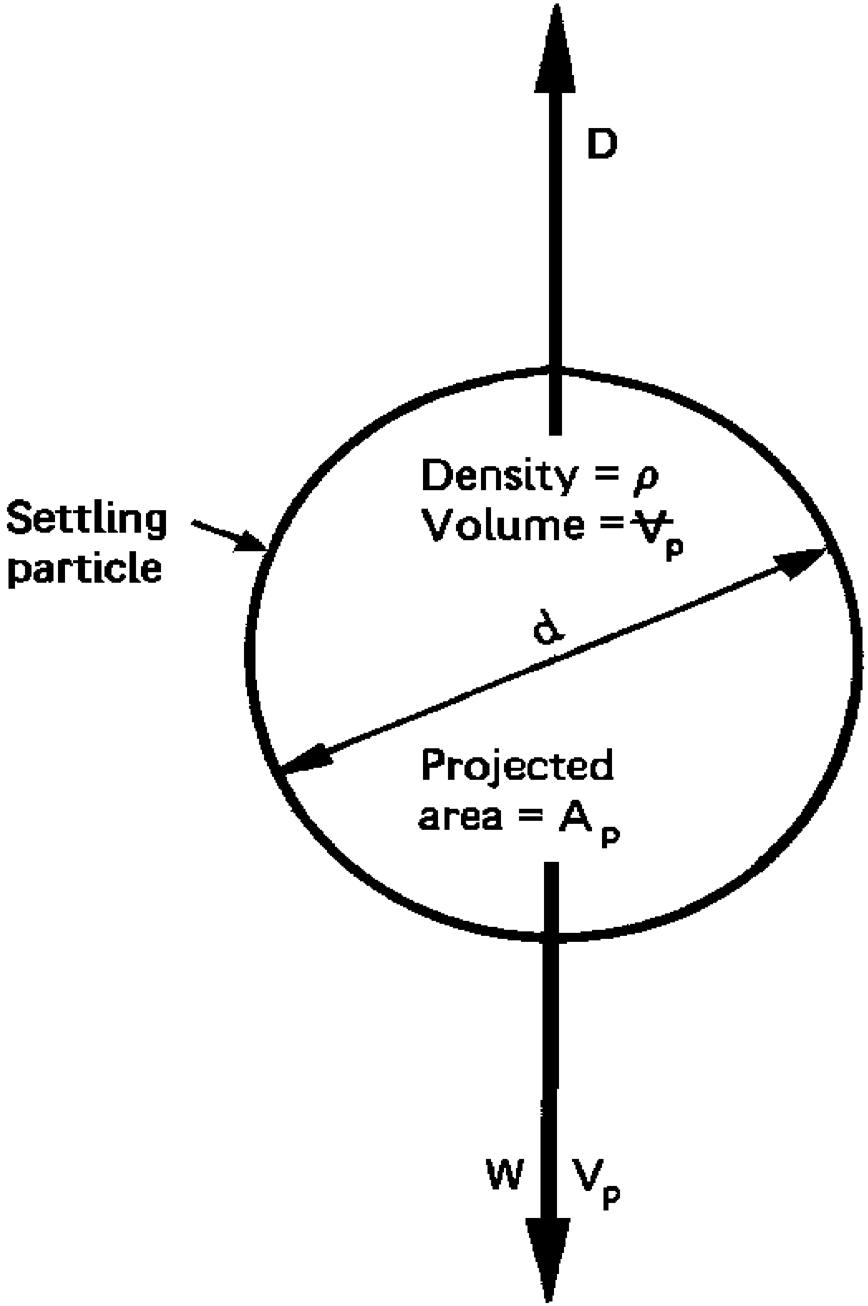


Solid- liquid separation in water treatment

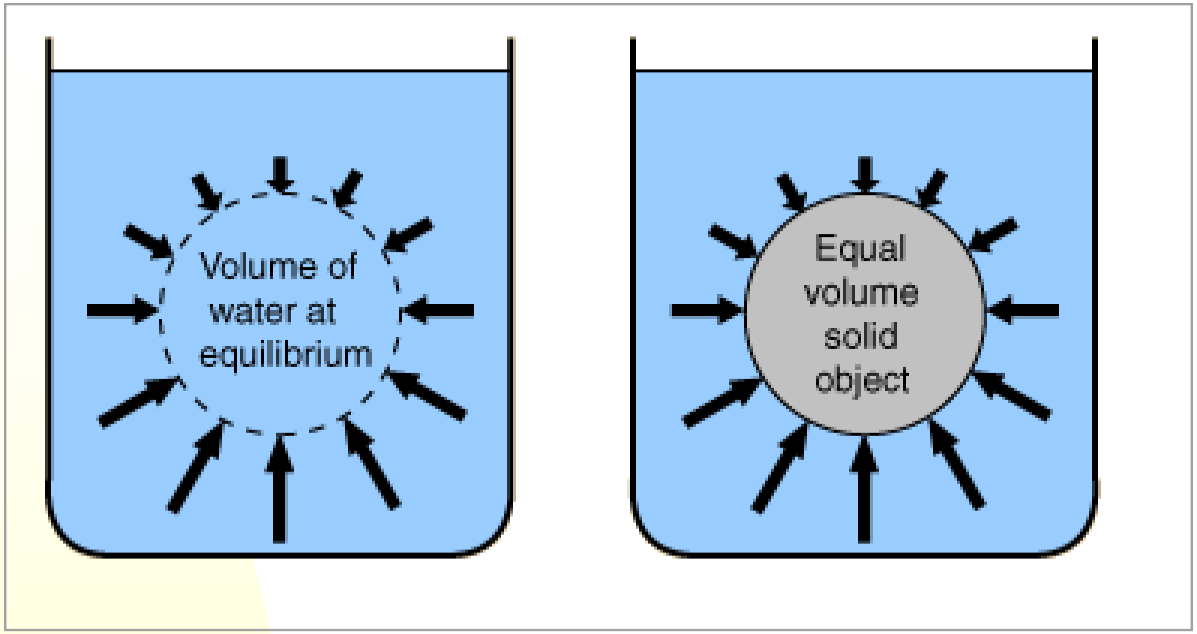


Typical layout of a water treatment plant

Analysis of Forces Acting On a Settling Particle



Archimedes's Principle



Examination of the nature of buoyancy shows that the buoyant force on a volume of water and a submerged object of the same volume is the same. Since it exactly supports the volume of water, it follows that the buoyant force on any submerged object is equal to the weight of the water displaced. This is the essence of Archimedes principle.

Terminal Velocity of a Particle

An expression for V_t from the submerged weight of the particle, W, and the fluid drag force, D.

The drag force on a particle is given by

$$D = C_D \rho_l A_p V_t^2/2$$

The submerged weight of the particle can be expressed as

$$W = (\rho - \rho_l) g \forall_s$$

Since D = W, **the above, after substituting A_p and $\forall_p$ for particle diameter d**

$$V_t = \sqrt{\frac{4(\rho - \rho_l)gd}{3\rho_l C_D}}$$

Stokes's Law

$R_e < 1,\ C_D = 24\,/Re$

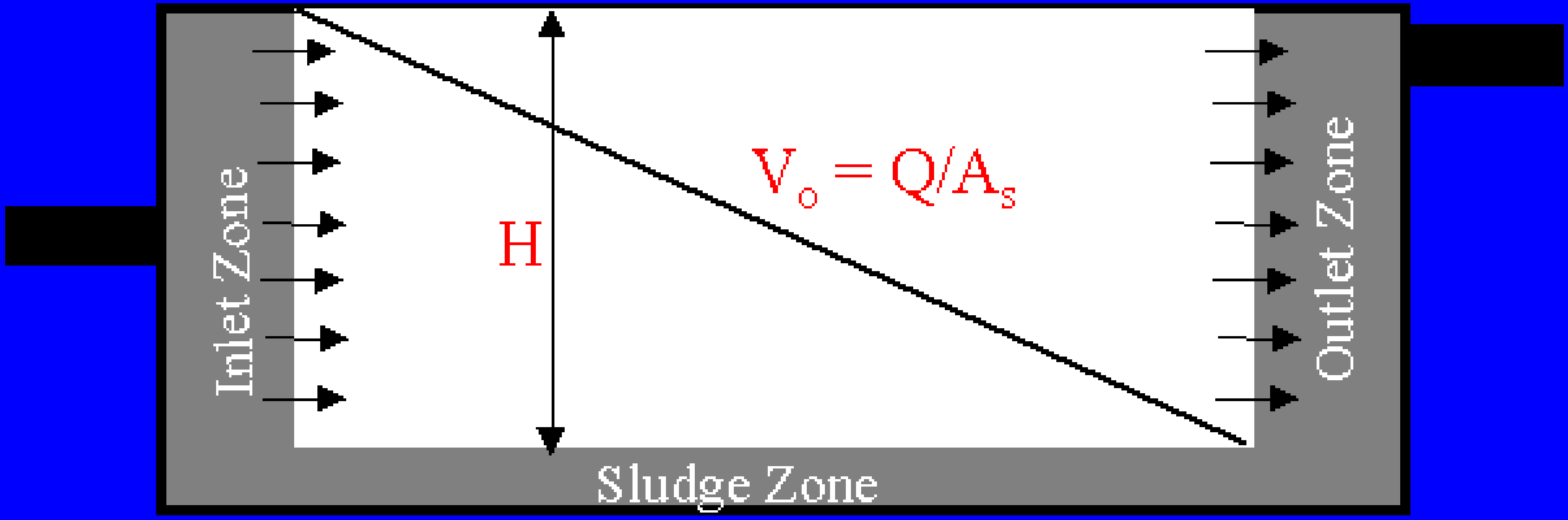
Substitute in the equation for v_t

$$V_t = \frac{g\,(\rho \;\; -\rho_l)\,d^2}{18\,\mu}$$

$$v_t = \frac{2\,(\rho \;\; -\rho_l)gr^2}{9\mu}$$

The upflow velocity in a settling tank needs to be < V_t

Sedimentation



$$v_o = \frac{H}{t_d} = \frac{H}{V/Q} = \frac{Q}{V/H} = \frac{Q}{A_s}$$

The overflow rate

Sedimentation

Typical design overflow rates for settling tanks are: 500-1000 gpd/ft^2 **(20-40 $m^3 m^{-2} d^{-1}$)**

All particles with a settling velocity greater than or equal to the overflow rate will be 100% removed.

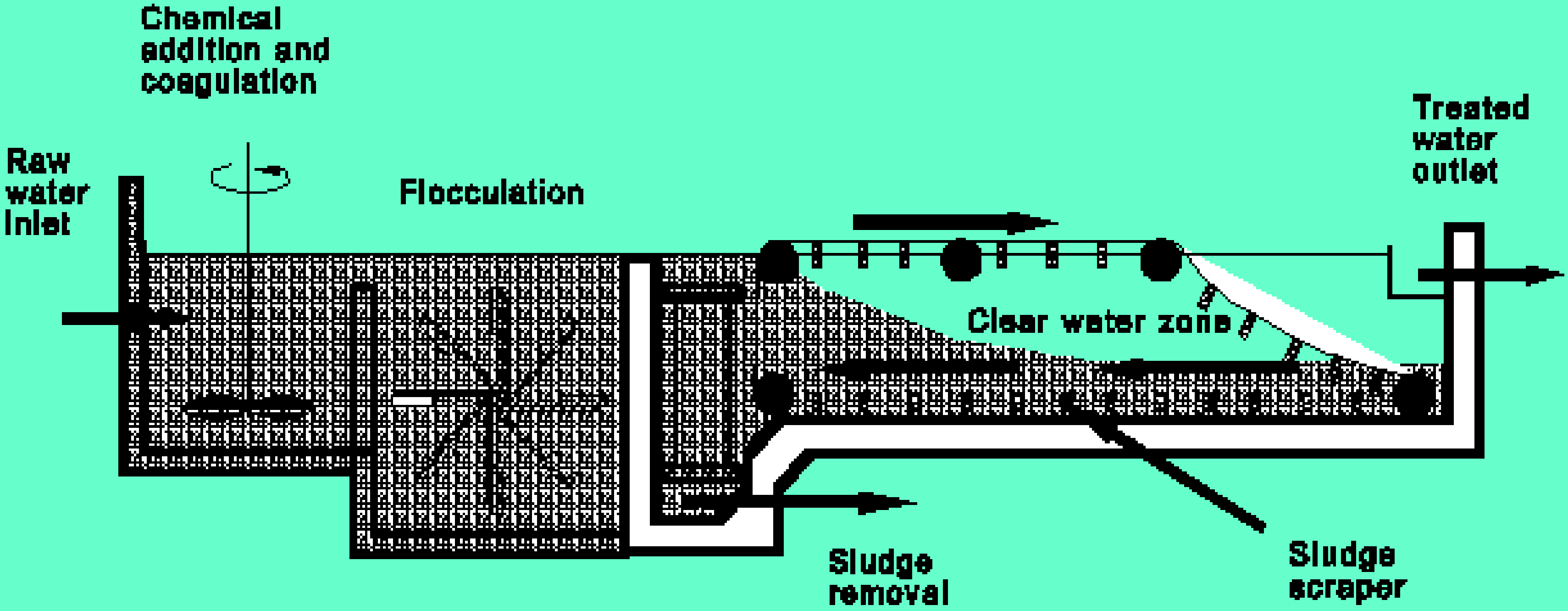
Particles with a lesser settling velocity will be removed to a fractional extent. Those that happen to enter the settling zone near the bottom will be completely removed and those that enter near the top will not.

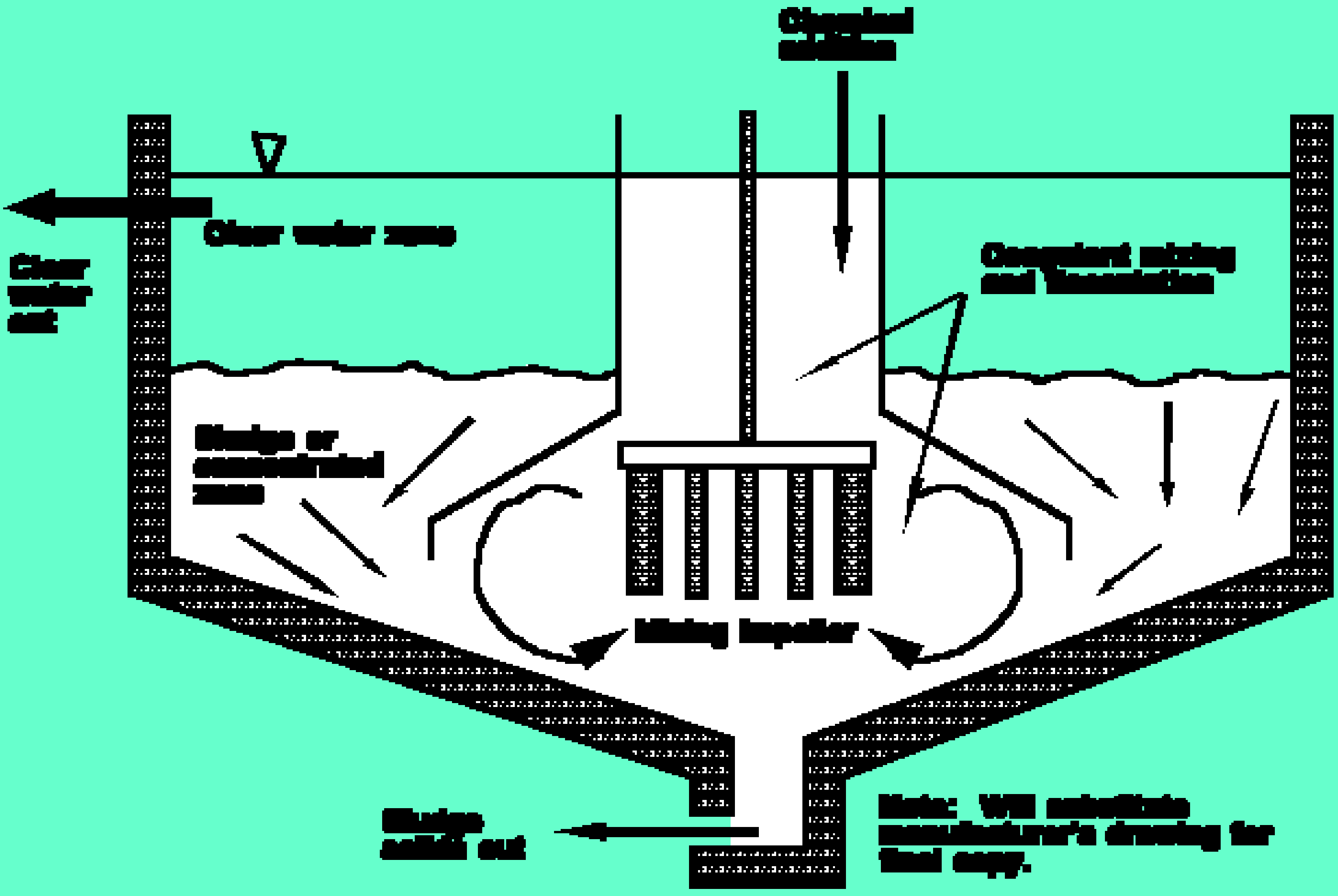
$$\text{Fraction Removed} = \frac{v}{Q/A_s}$$

Sedimentation Tank Configurations

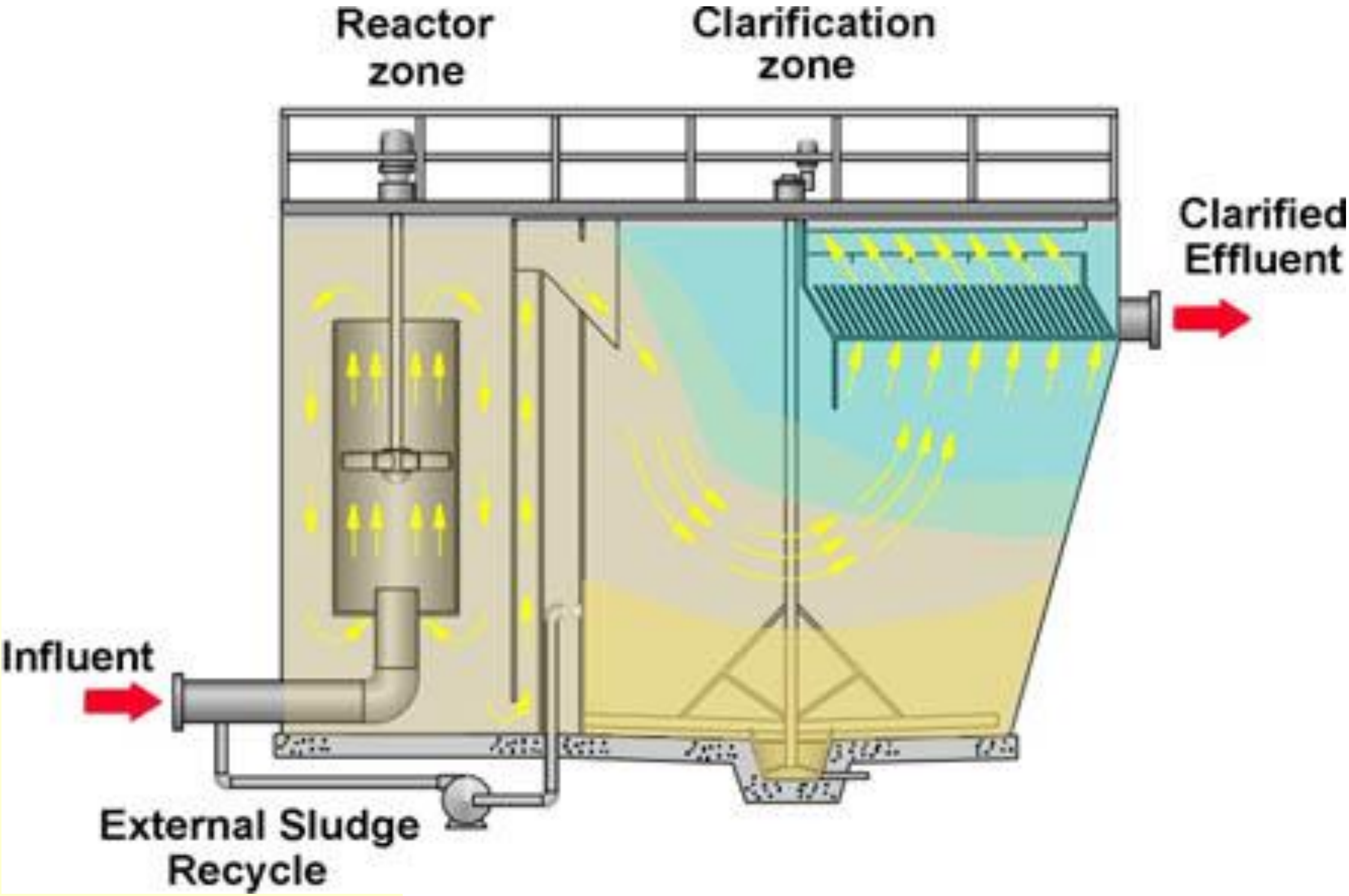
- Rectangular Clarifiers
  - most common
- Circular clarifiers
  - Center feed
  - Peripheral feed
- Flocculator-Clarifiers

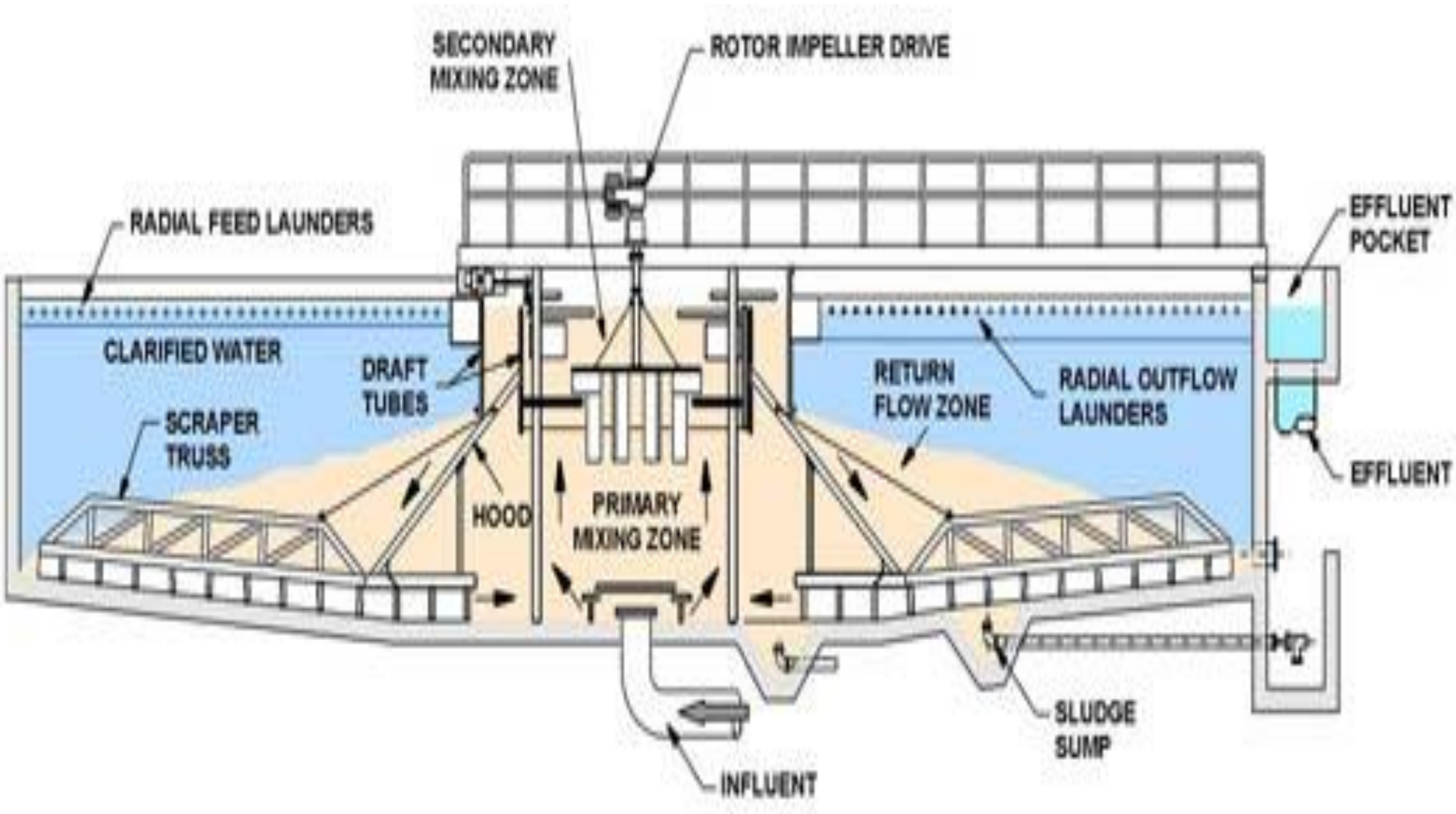
Typical rectangular clarifier

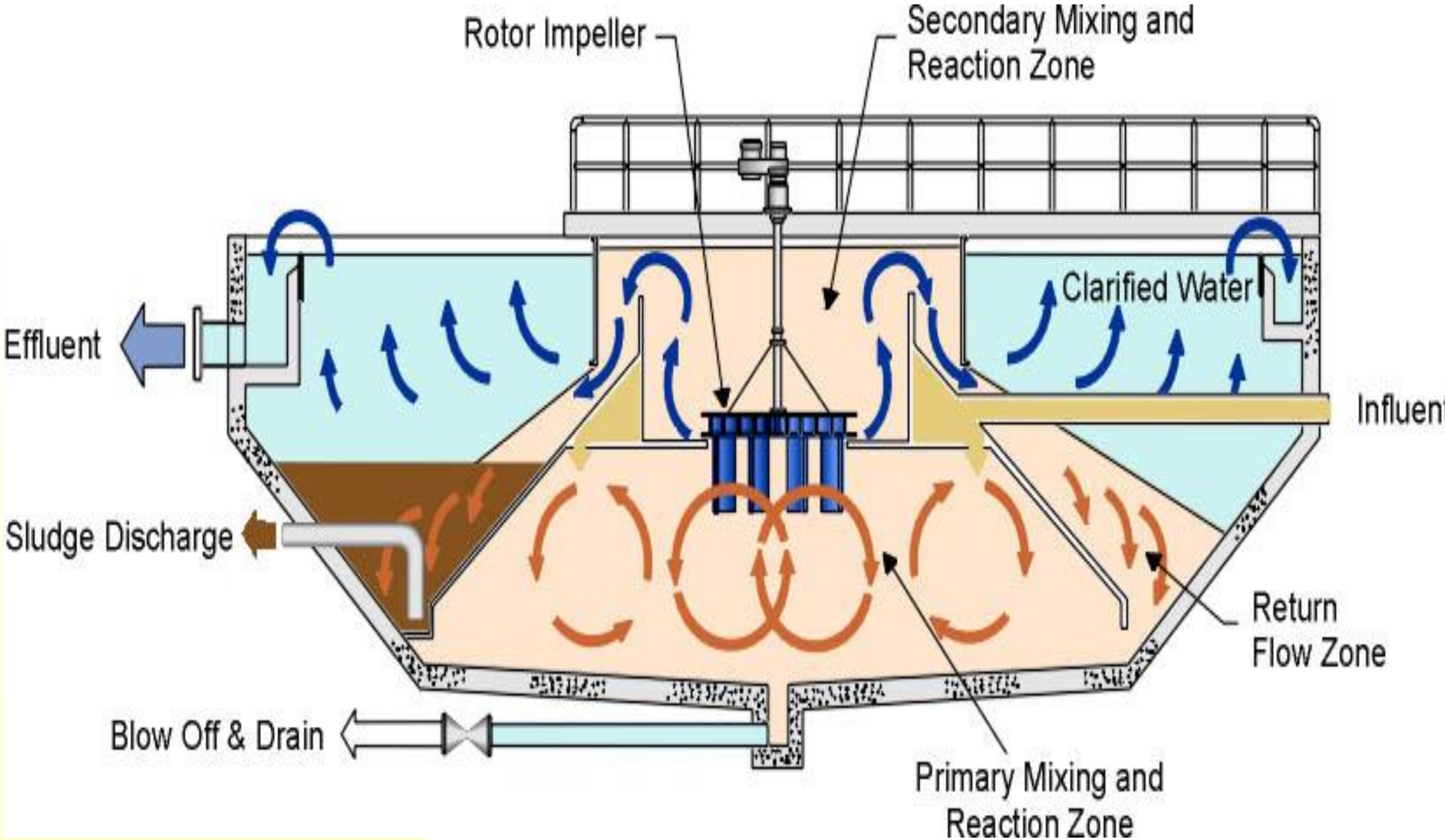




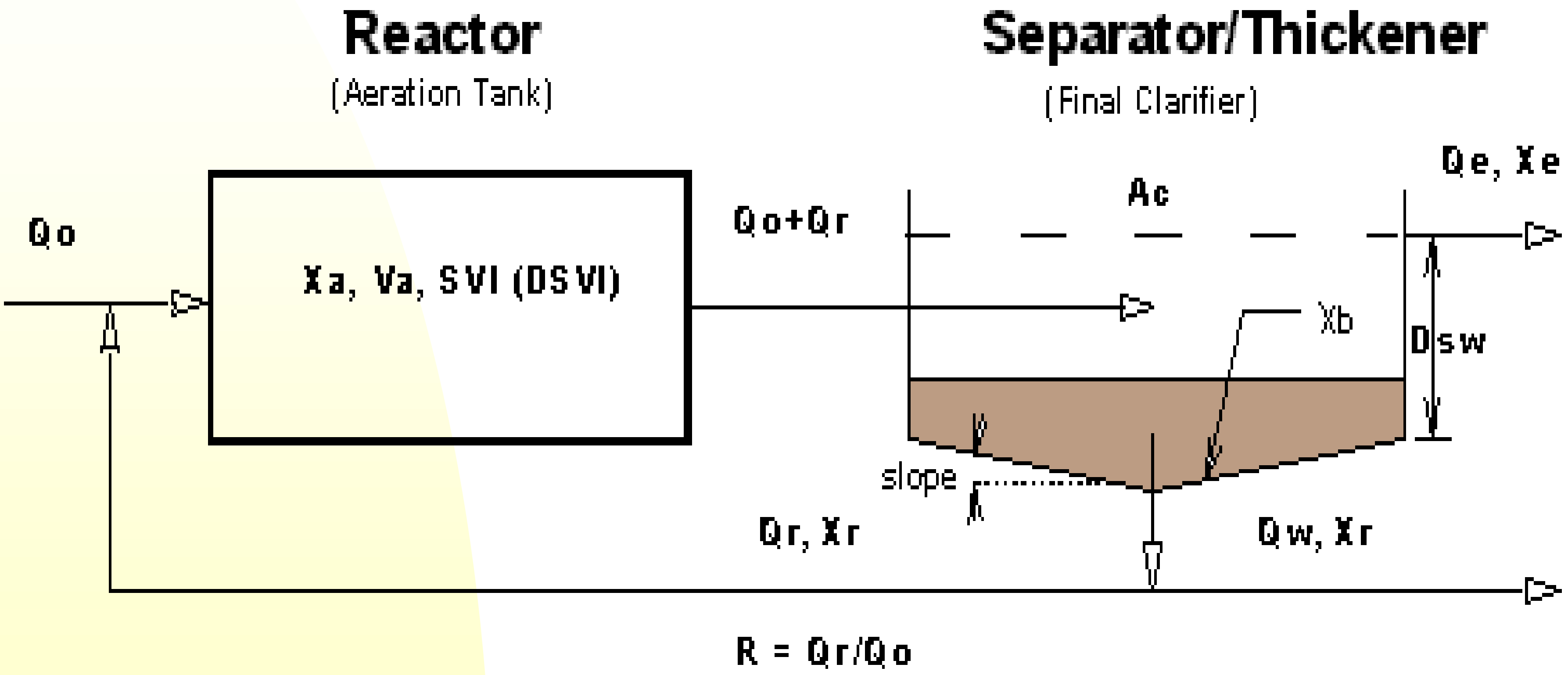
Chemical addition
Clear water zone
Clear water out
Coagulant mixing and flocculation
Sludge or concentrated zone
Mixing impeller
Sludge solids out
Note: Will substitute manufacturer's drawing for final copy.


Reactor zone
Clarification zone
Clarified Effluent
Influent
External Sludge Recycle


SECONDARY MIXING ZONE
ROTOR IMPELLER DRIVE
RADIAL FEED LAUNDERS
EFFLUENT POCKET
CLARIFIED WATER
DRAFT TUBES
RETURN FLOW ZONE
RADIAL OUTFLOW LAUNDERS
SCRAPER TRUSS
EFFLUENT
HOOD
PRIMARY MIXING ZONE
SLUDGE SUMP
INFLUENT

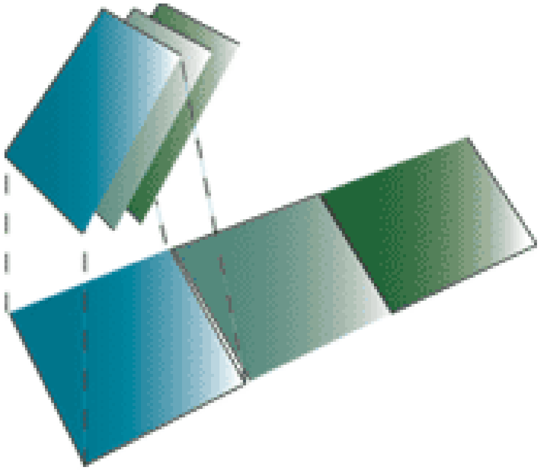

Rotor Impeller
Secondary Mixing and
Reaction Zone
Clarified Water
Effluent
Influent
Sludge Discharge
Return
Flow Zone
Blow Off & Drain
Primary Mixing and
Reaction Zone

Activated Sludge Mass Balance over Settler



Weir Details

LAMELLA SETTLING TANKS:
Shortening the settling distance



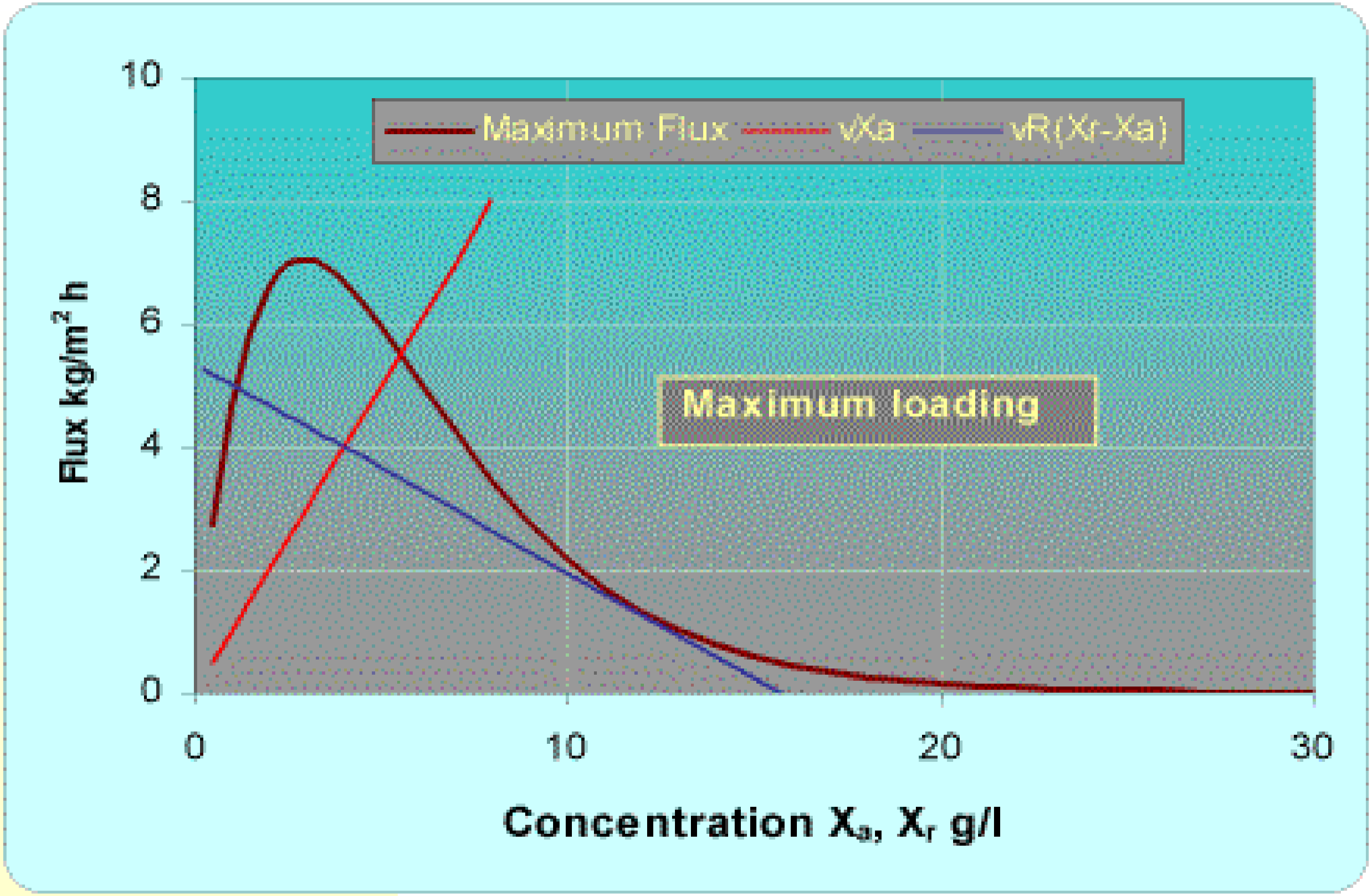
Pipe bundles also used

Sedimentation Tank Design

- Side water depth: about 12 ft.
- settling velocities: 2-6 ft/hr
- retention time: 4-8 h[redacted]
- overflow rates: 500-1000 gpd/ft^2 or 0.3-0.7 gpm/ft^2 **(20 – 40 m^{3}m^{-2}d^{-1} or 0.8 – 1.7 m/h)**
- linear velocities: less than 0.5 ft/min

  (2.5 mm/s) – limits weir loading rate to 100 – 200 m^{3}m^{-1}d^{-1}

Sludge Thickening Design



FLOTATION

Separation of low density flocs

If flocs have a density very close to that of water, it may be necessary to decrease their density by adding gas bubbles

FLOTATION

Separation of low density flocs

Methods of forming gas bubbles

- Diffusion
- Vacuum
- Electrolysis
- Dissolved air

Surface Tension and Bubbles

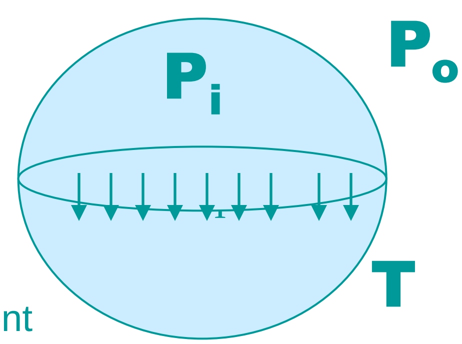
• The surface tension of water provides the wall tension for the formation of bubbles. To minimize the wall tension the bubble pulls into a spherical shape (LaPlace's law).

• Pressure difference between the inside and outside of a bubble depends upon the surface tension and the radius of the bubble. Visualize the bubble as two hemispheres

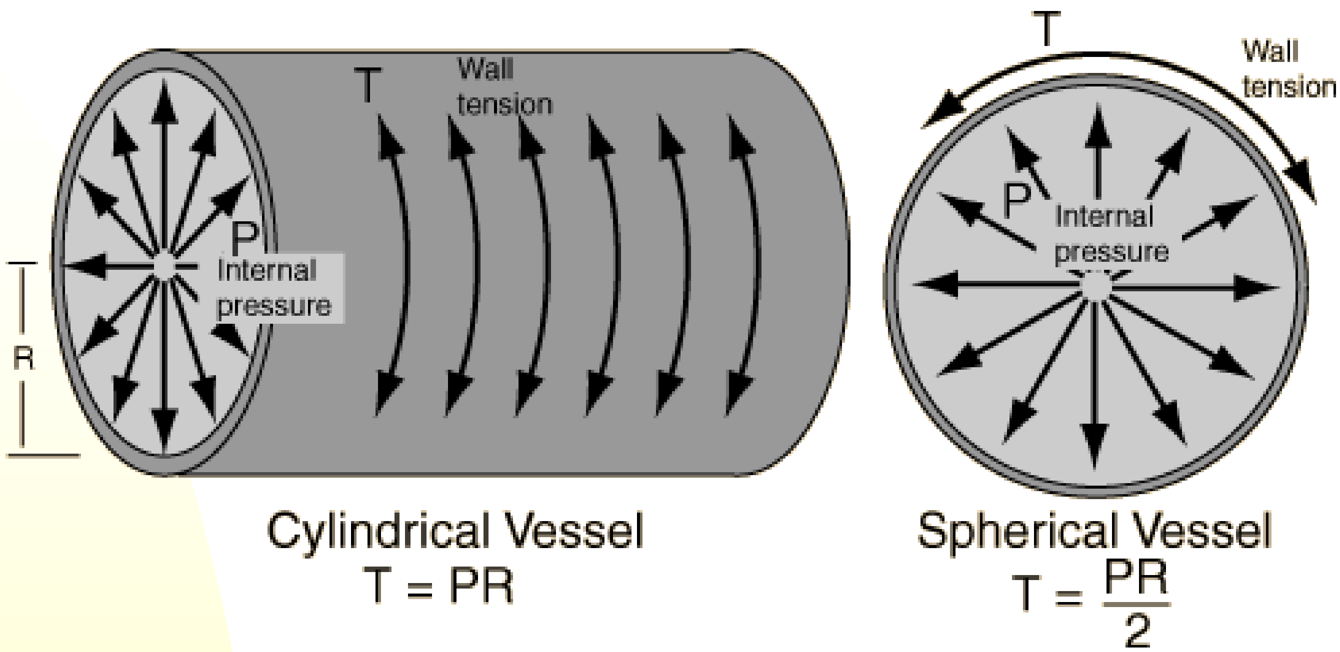
• Note the internal pressure which tends to push the hemispheres apart is counteracted by the surface tension acting around the circumference of the circle.

• For a bubble with two surfaces providing tension, the pressure relationship is:

$$P_i - P_o = 4T/r$$



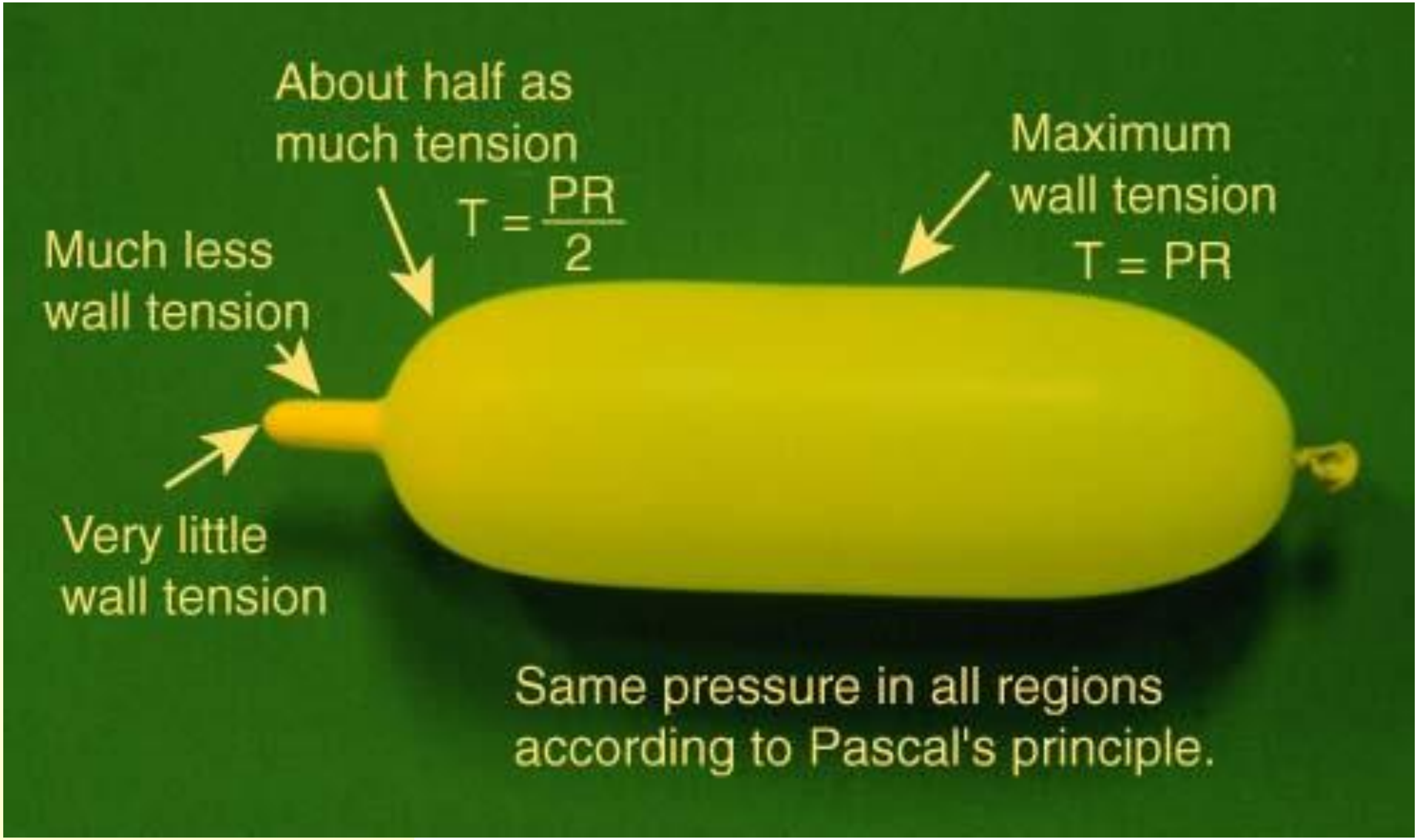
La Place's Law



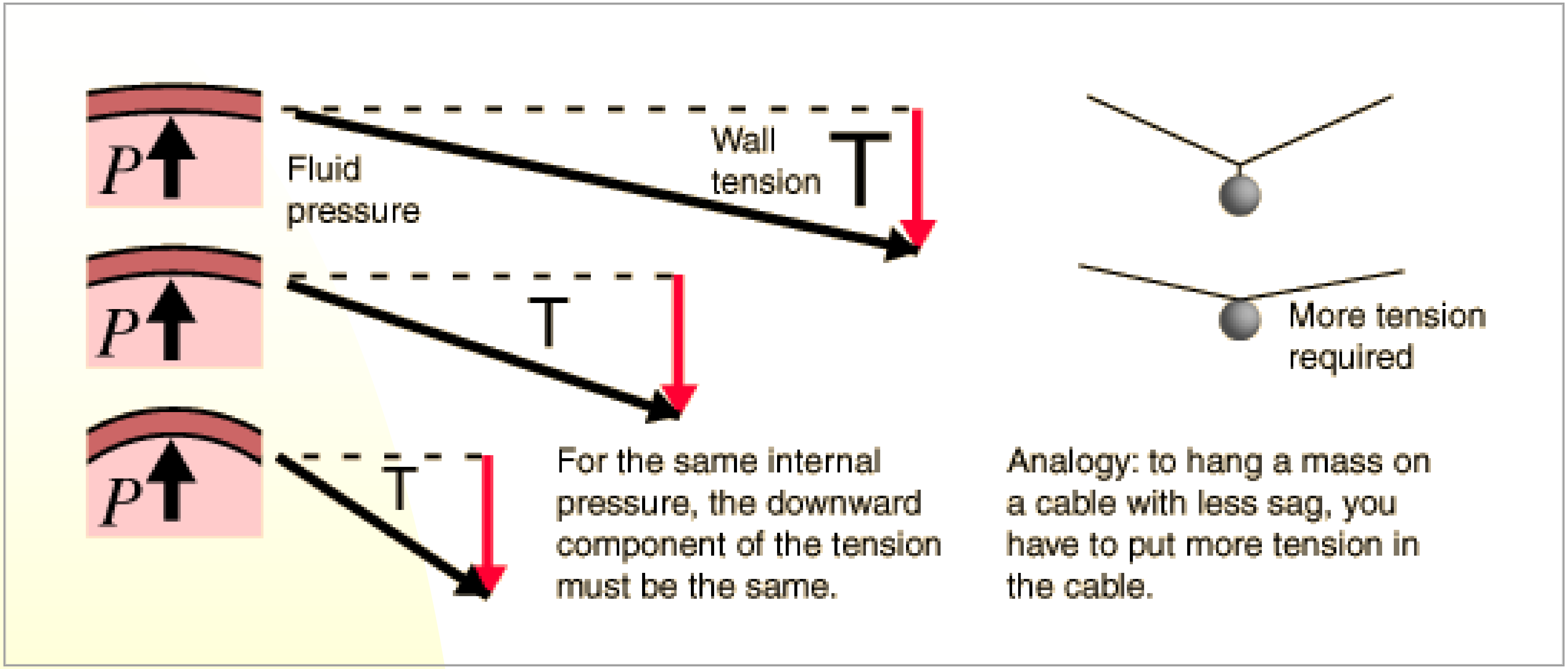
The larger the vessel radius, the larger the wall tension required to withstand a given internal fluid pressure.

For a given vessel radius and internal pressure, a spherical vessel will have half the wall tension of a cylindrical vessel.

Wall Tension



Why does wall tension increase with radius?



If the upward part of the fluid pressure remains the same, then the downward component of the wall tension must remain the same. If the curvature is less, then the total tension must be greater in order to get that same downward component of tension.

Bubble Pressure

- Net upward force on the top hemisphere of the bubble:

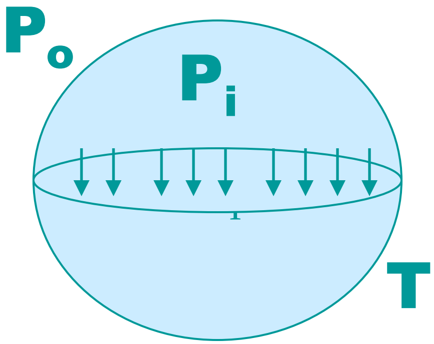
$$F_{upward} = (P_i - P_o)\pi r^2$$

- The surface tension force downward around circle is twice the surface tension times the circumference, since two surfaces contribute to the force:

$$F_{downward} = 2T(2\pi r)$$

$$P_i - P_o = 4T/r \text{ for a spherical bubble}$$

$$P_i - P_o = 2T/r \text{ for half a bubble}$$



Attachment to floc

- **Ratio of area/volume increases with decreasing size**
- **Forces acting on a gas bubble:**

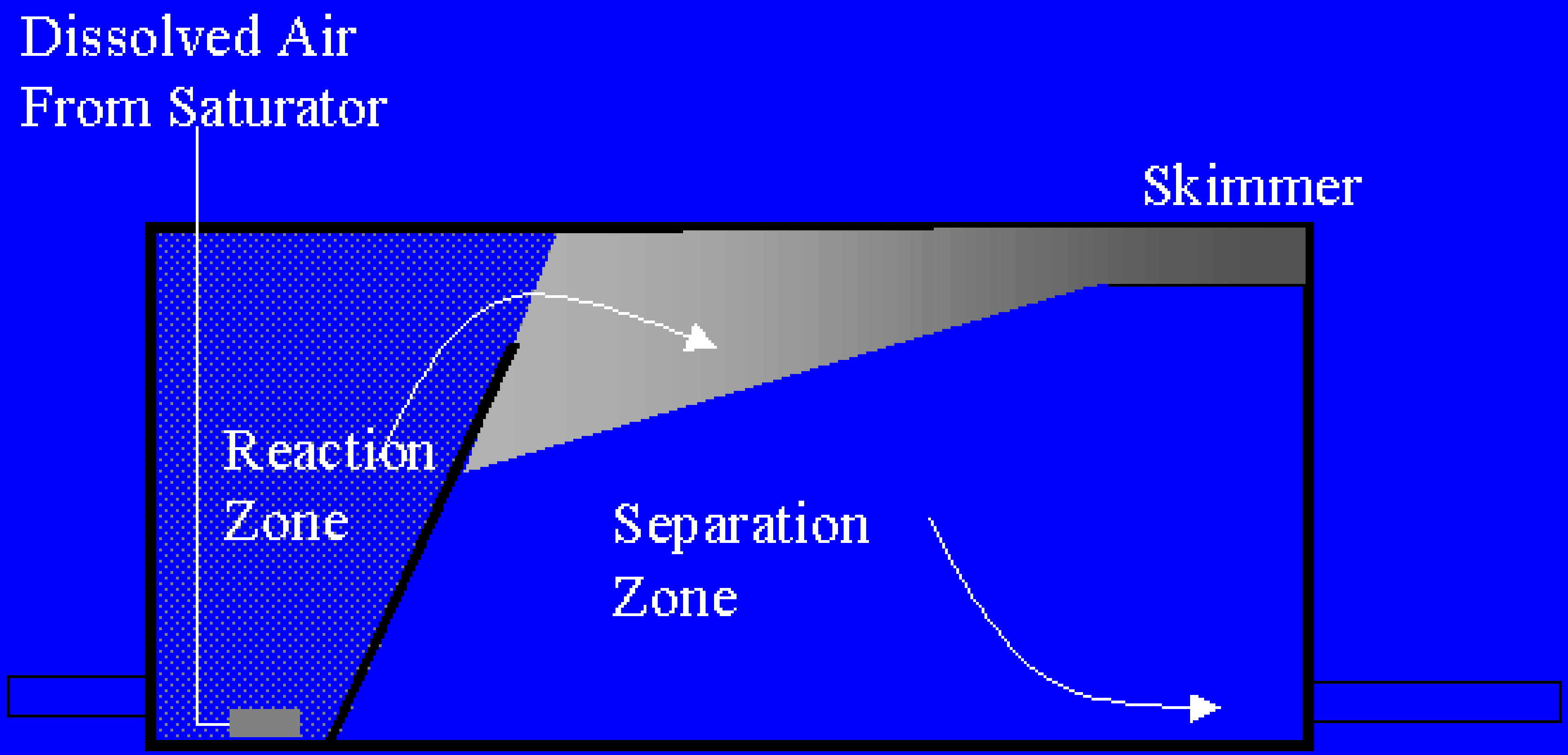
  Internal pressure x area

  = surface tension x circumference
- **Easier for bubble to form against solid**

Dissolved Air Flotation (DAF)

- Alternative to Sedimentation
- Particles attach to air bubbles
- Best for removing low density floc
- Uses small tanks
  - high hydraulic loading (4-6 gpm/ft^2)
  - low detention times (~10 min)
- higher sludge solids conc.

DAF Schematic



Stokes's law for flotation

For Gravity Settling:

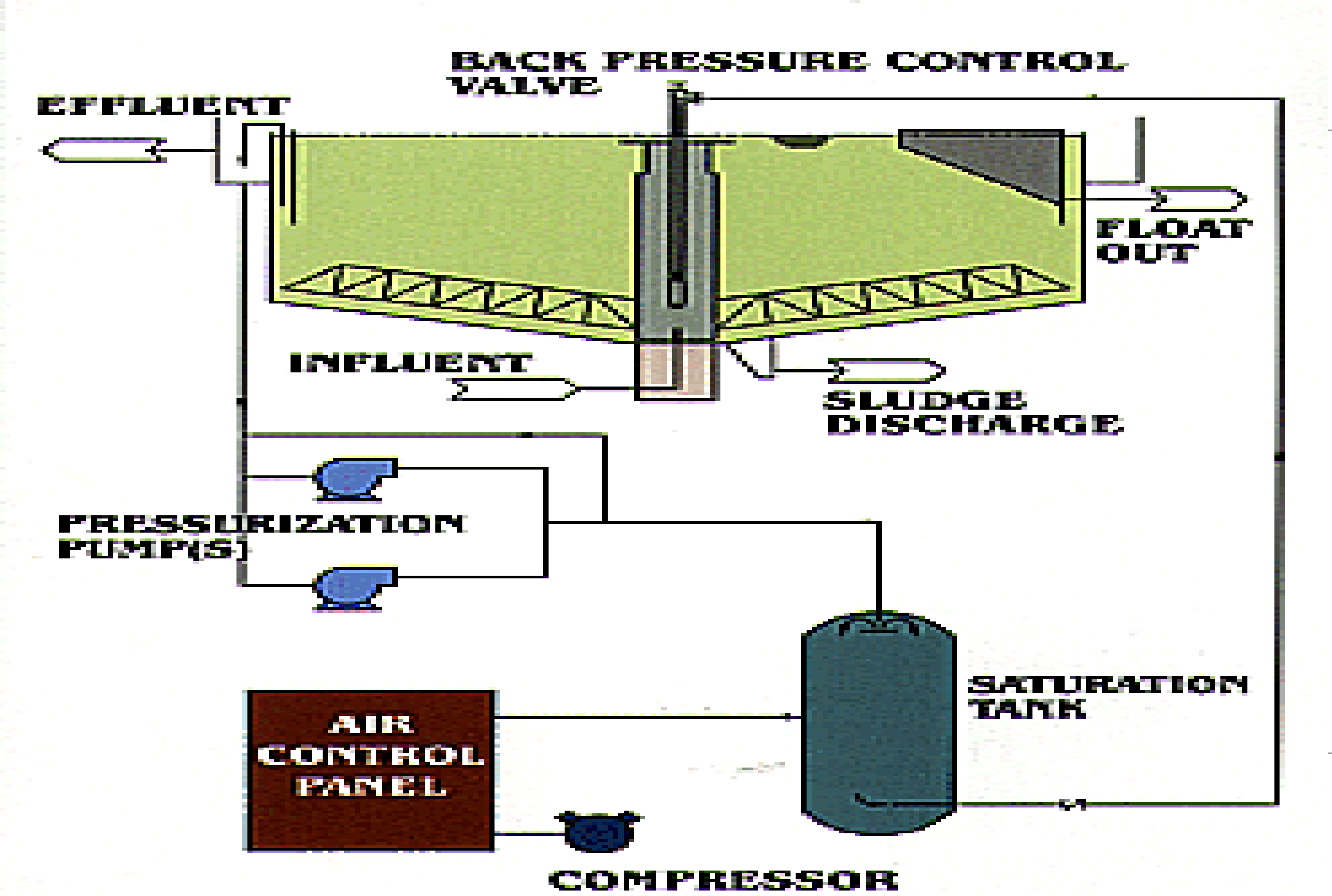
$$v_p = \frac{(\rho_p - \rho_w) d^2 g}{18\mu}$$

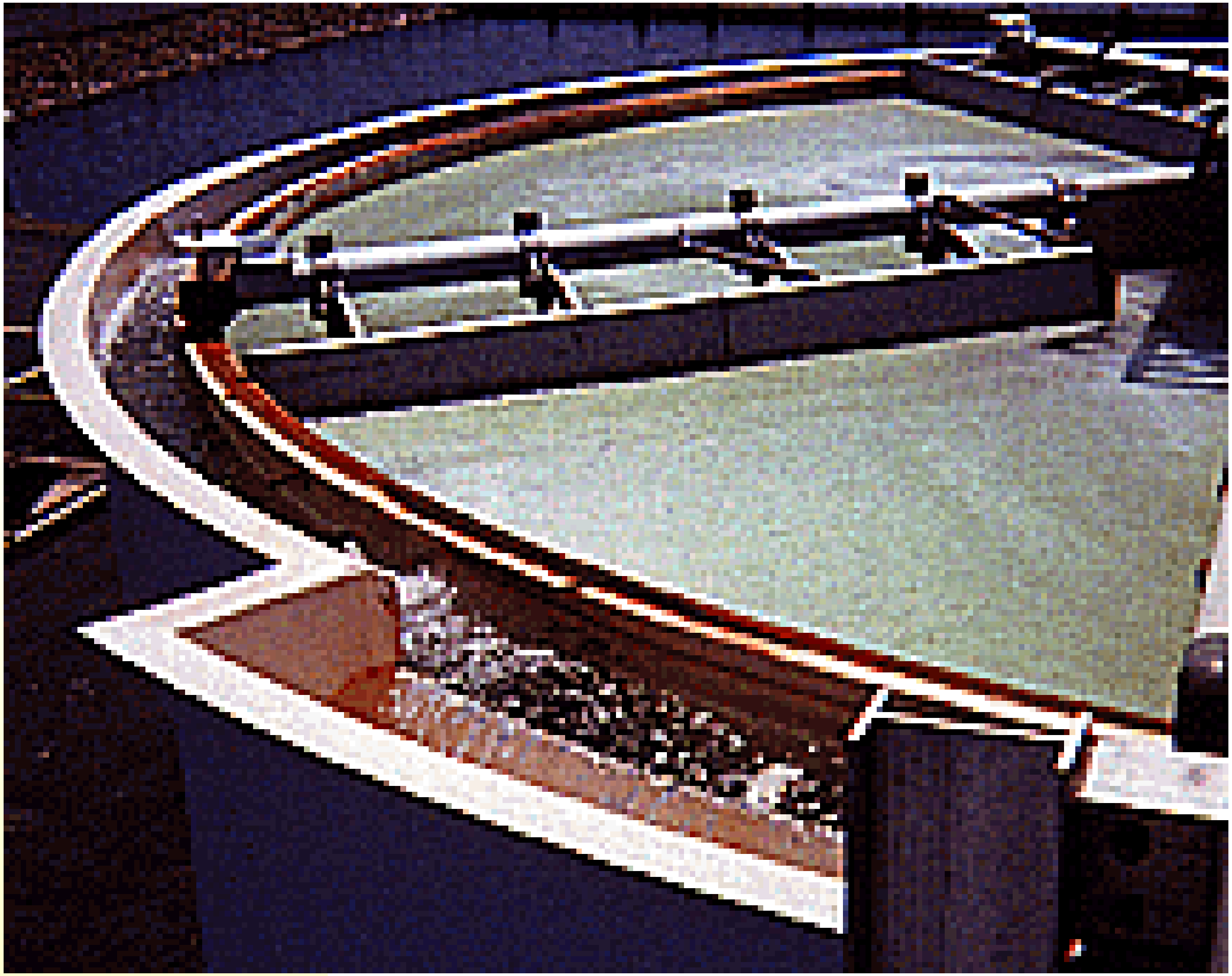
For DAF:

$$v_{pb} = \frac{(\rho_w - \rho_{pb}) d_{pb}^2 g}{18\mu}$$

Density and diameter of the Particle-bubble agglomerate (p_{pb} and d_{pb}) are determined from simple geometry.

Essential Elements in a Flotation Unit Process



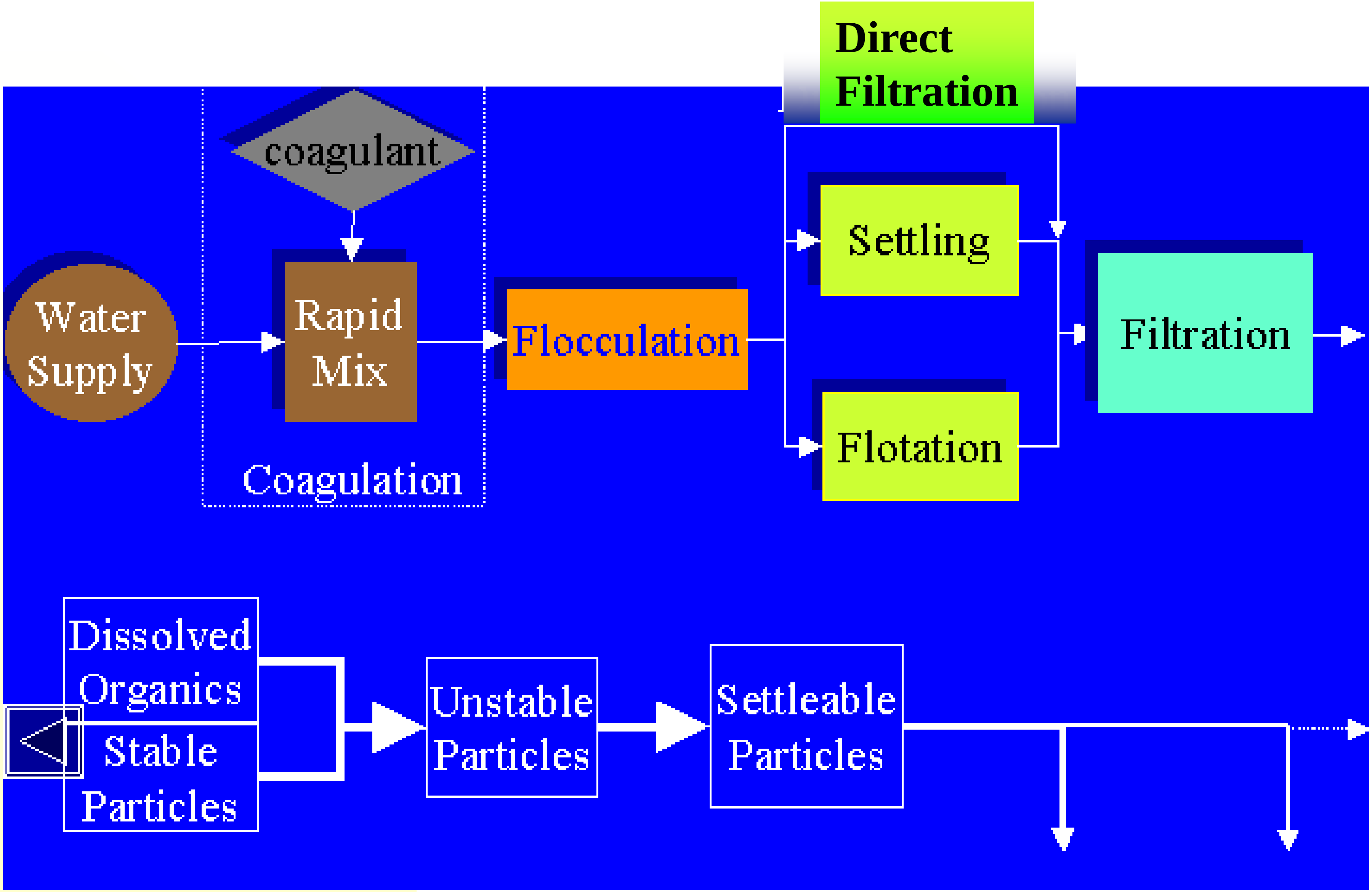


Dissolved Air Flotation


BOTTOM SLUDGE

Saturation tank for flotation

Overview of solid-liquid separation alternatives in water



Softening

- Addition of:
  - Lime ($Ca(OH)_2$)
  - Soda Ash (Na_2CO_3)
- Removes calcium and magnesium
- Removes particles
- Can also remove some DOC, but not as much as coagulation
- Uses high pH

Hardness Classification

Description of Hardness	Hardness, as mg $CaCO_3$/L
Soft	< 50
Medium	50 to 150
Hard	150 to 300
Extremely hard	> 300

Softening Chemistry

Stoichiometry

$$Ca(OH)_2 + HCO_3^- + Ca^{+2} \rightarrow 2CaCO_3 \downarrow + 2H_2O$$

$$Mg^{+2} + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + Ca^{+2}$$

Thermodynamics

$$[Ca^{+2}][CO_3^{-2}] = 10^{-8.15}$$

$$[Mg^{+2}][OH]^2 = 10^{-9.2}$$

What you need to be able to do

- Be able to size settling tanks on the basis of particle settling rates and identify important zones in the settling tank
- Be able to do a mass balance over a flotation unit to account for air usage
- Be able to size a flotation unit based on particle sizes and densities