# Today's Lecture

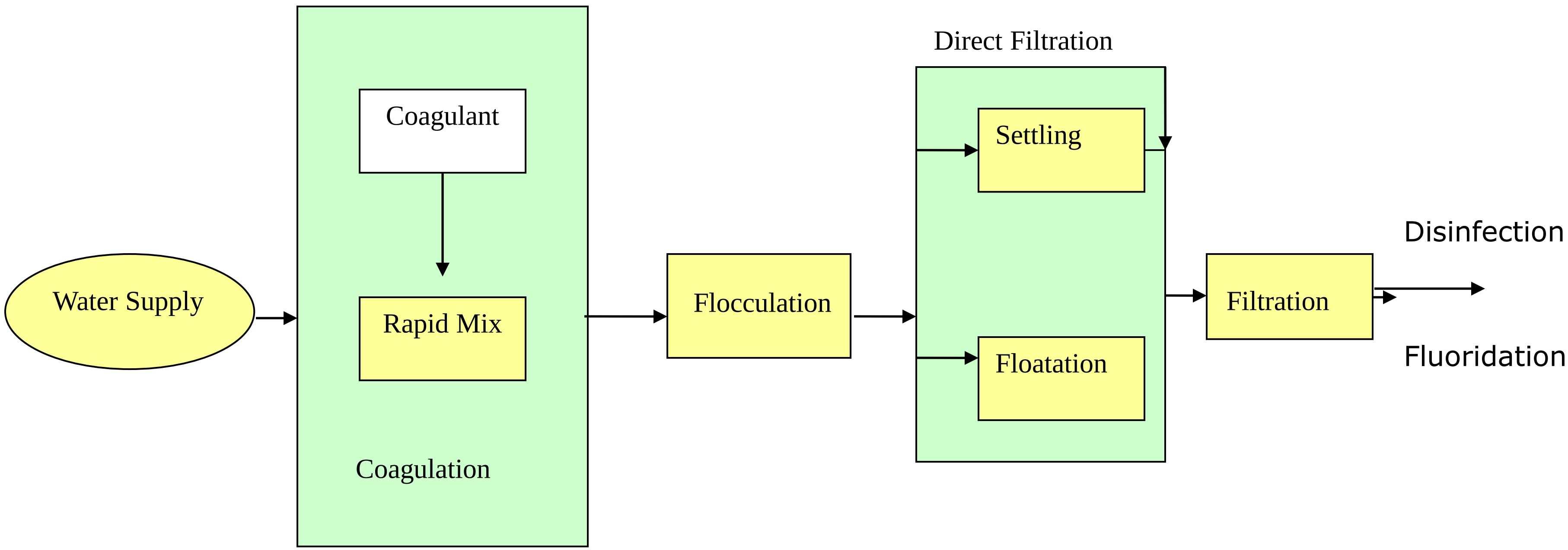
- Introduction to Water Treatment System
  - Coagulation and Flocculation
  - Sedimentation
  - Filtration
  - Disinfection

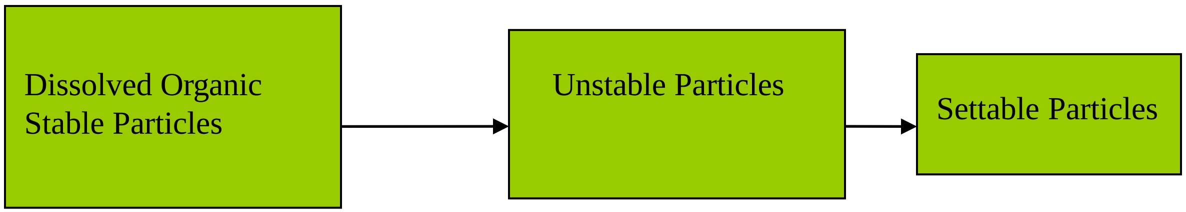
# Water Treatment System

- Bring raw water up to drinking water quality
- Sources
  - Surface water
  - Groundwater

| Groundwater | Surface water |
|---|---|
| Low turbidity | Higher turbidity |
| Low microbial contamination | Low microbial contamination |
| May have hardness, metals, odors | Low hardeness |
| May require softening | Easy access |
| | Must be filtered |

# Filtration


Water Supply
Coagulant
Rapid Mix
Coagulation
Flocculation
Direct Filtration
Settling
Floatation
Filtration
Disinfection
Fluoridation

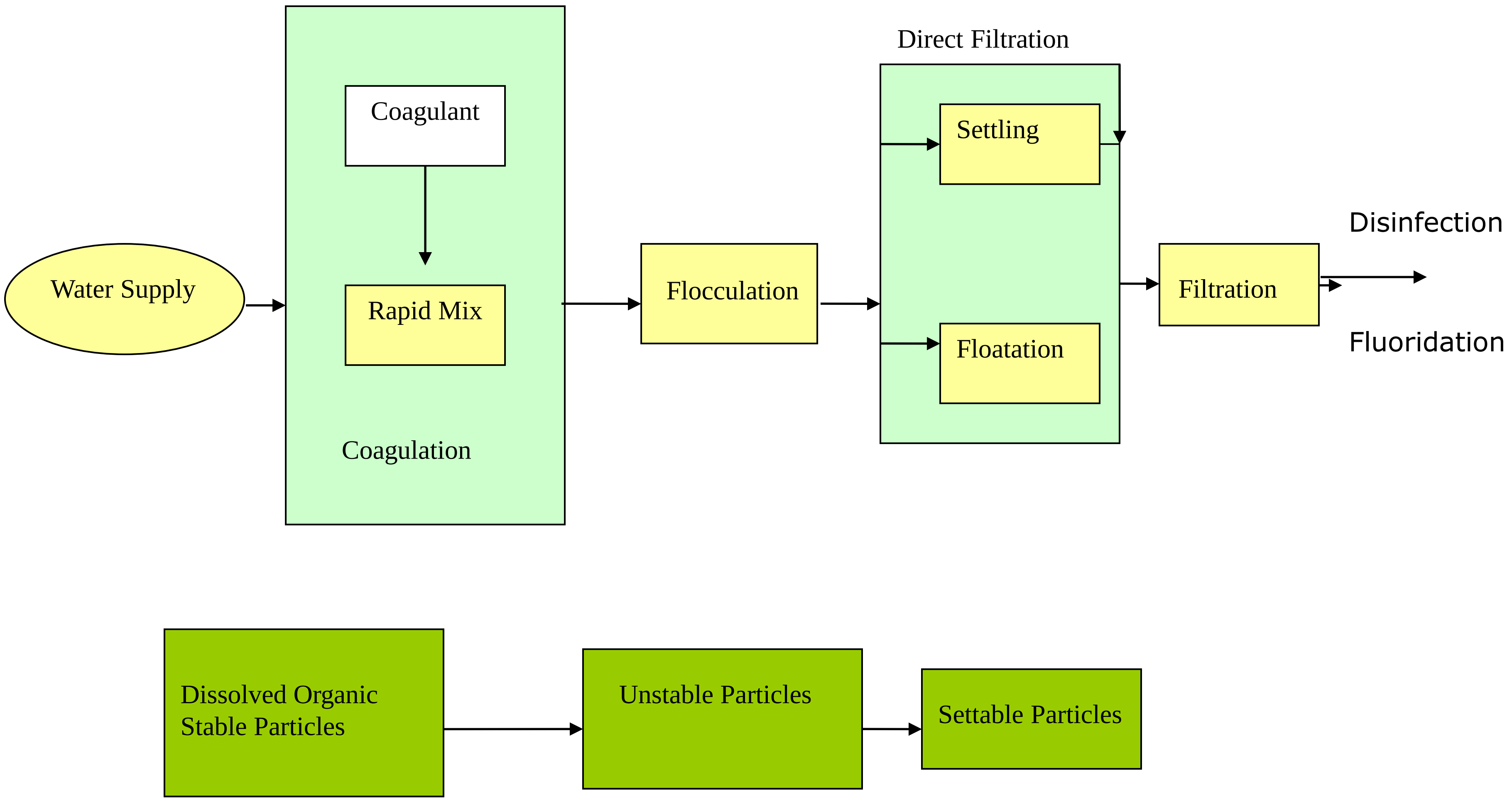

Dissolved Organic
Stable Particles
Unstable Particles
Settable Particles

# Objective:

- Understand the main process in Water treatment plant

# Coagulation and Flocculation

# Coagulation and Flocculation



# Introduction

- Particles in Water

| Organic | Inorganic |
|---|---|
| Viruses | Clay |
| Bacteria | Silts |
| Algea | Mineral oxide |
| Protozoan cyst and oocyst | |
| NOM<br>(particulate and dissolved organic matter as humic acid) | |

# Introduction

- Why we care ?
  - Turbidity
    - How to measure??
    - **unit** is NTU,. or Nephelometric turbidity units
  - Disease
  - Disinfection by product formation
  - Hardness
  - Color

# Properties and stability of particles

- Particle size

| Class | Size (m) | Settling velocity |
|---|---|---|
| Macromolecules | ~$10^{-9}$ | 3 m/$10^6$ yr |
| Colloidal particles | ~ $10^{-8}$- $10^{-6}$ | 0.3 m/y |
| Silts | ~ $4\times10^{-6}$ - $6\times10^{-5}$ | 9 m/d |
| Sand | ~ $6\times10^{-5}$- $2\times10^{-3}$ | 1-10 m/min |

- Note: Can you separate Colloidal and macromolecules by gravity?

# Introduction

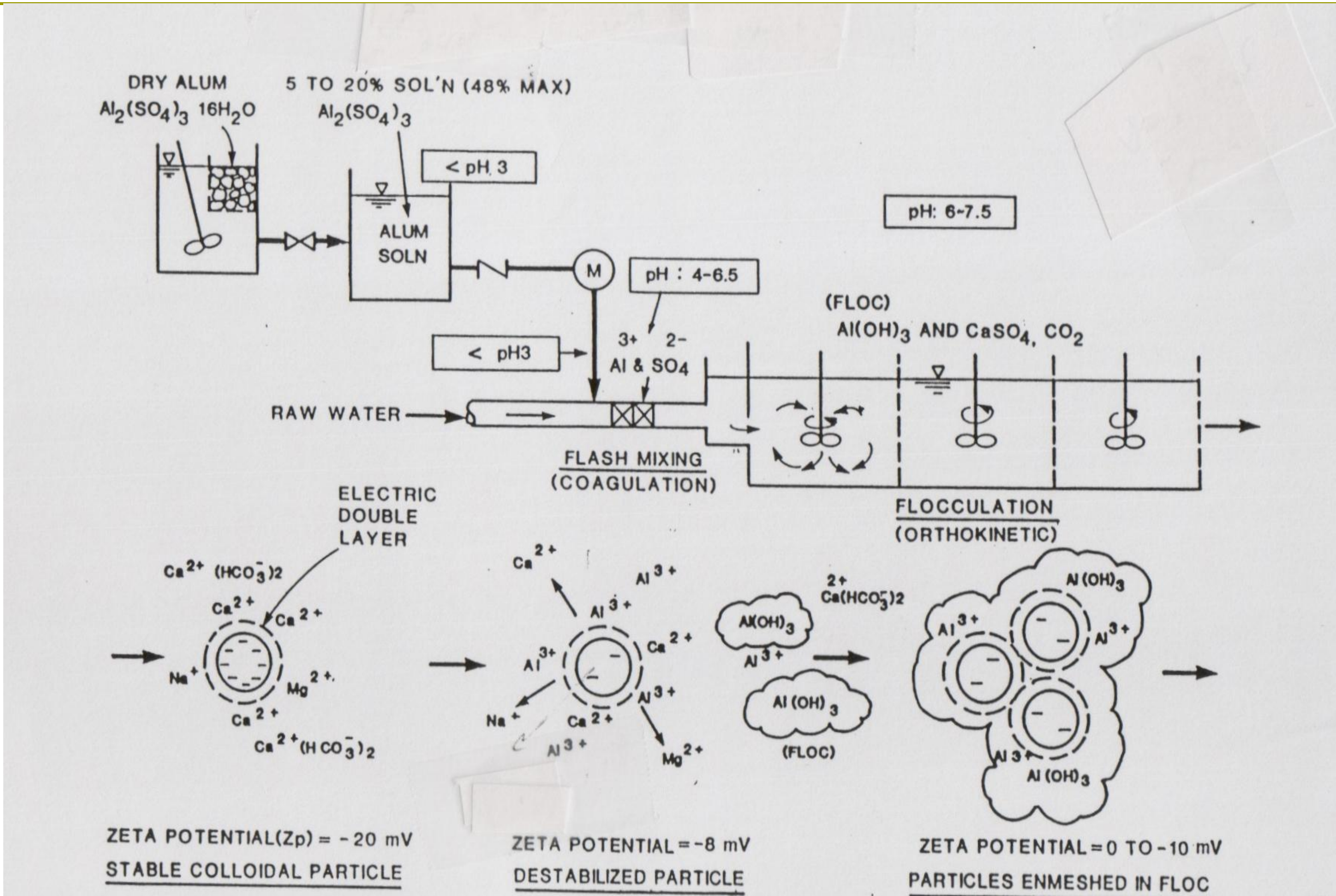
- Removal Approach
  - Large particles-
    - Settle rapidly with gravity
  - Small particles
    - destabilize colloids so they aggregate

- Note:
-  Particles suspension are thermodynamically unstable

# Coagulation Vs Flocculation

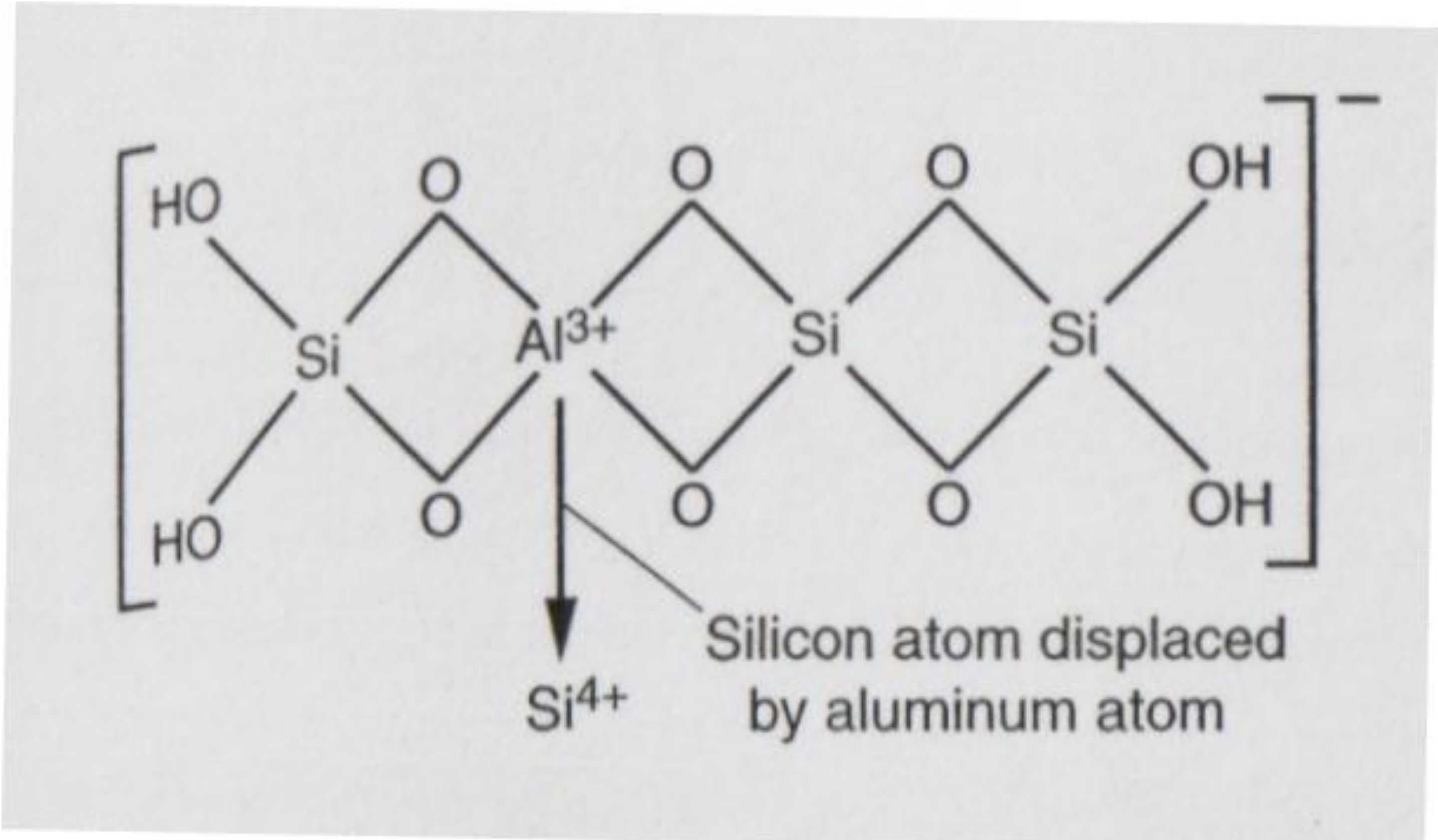
- Coagulation
  - Addition of chemical coagulant or coagulants
  - Particles destabilization
    - Reduction of electrical surface charge
  - Less than 10 s
- Flocculation:
  - Particle aggregation (Sticking of destabilized particles)
  - 20-45 min
  - Floc separate  by gravity

# Coagulation practice-Inorganic Coagulant



# Properties and stability of particles

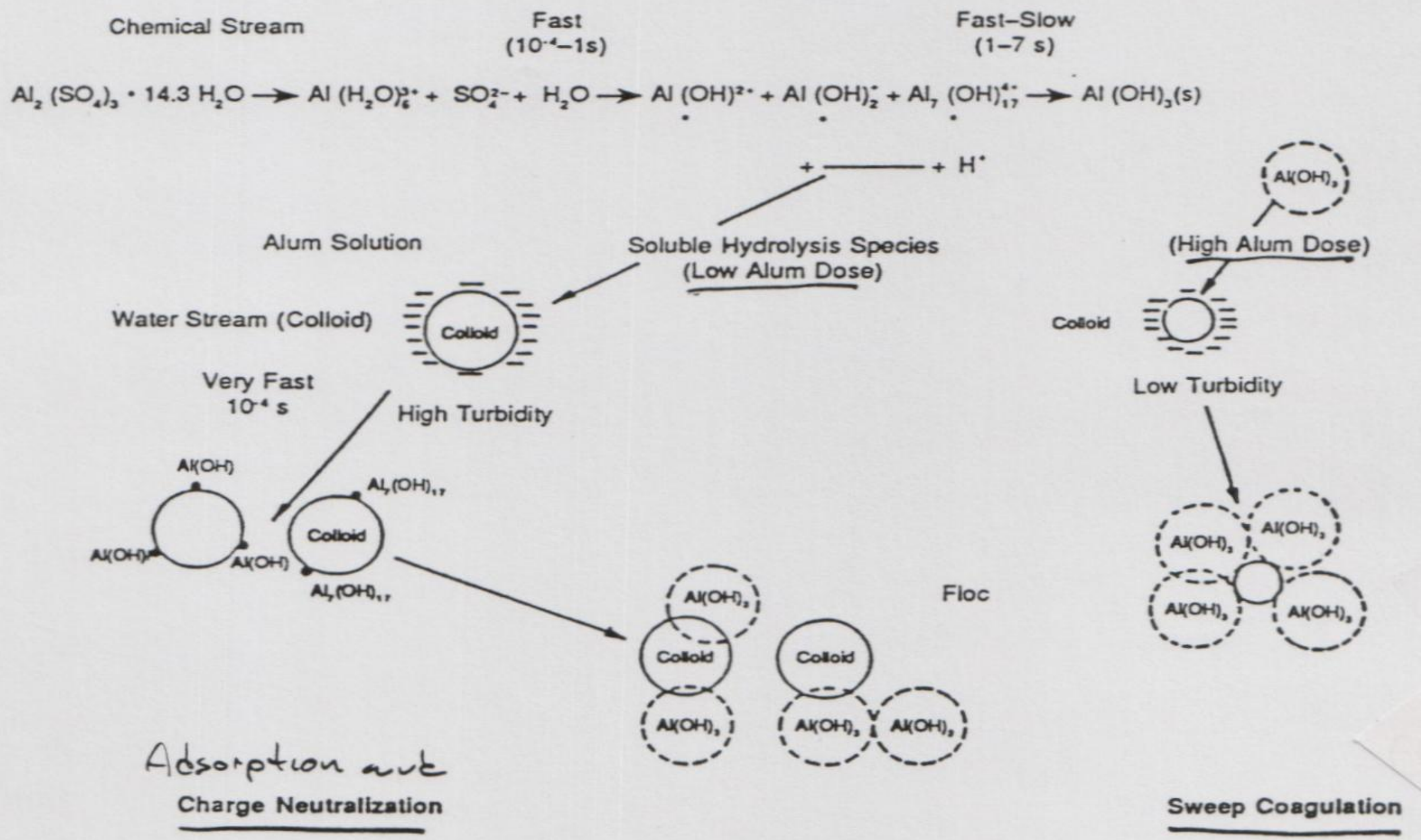
- Particle solvent interactions
  - Surface charge
    - Isomorphous replacement



# Coagulation

- Coagulation mechanism
  - Compression of the electrical double layer
  - Adsorption and charge neutralization
  - Adsorption and inter particle bridging
  - Enmeshment in a precipitate (Sweep floc)

# Coagulation practice-Inorganic Coagulant

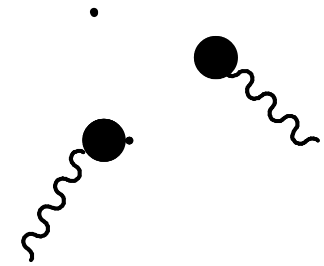



*Source: Amirtharajah, A. & Mills, K.M. 1982. Rapid-Mix Design for Mechanisms of Alum Coagulation.* Jour. AWWA, *74:4:210.*

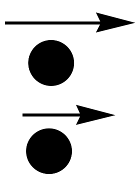
Figure 1-2 Reaction schematics of coagulation.

# Floculation Mechanism

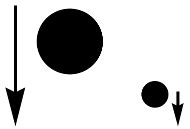
- Random collision Brownian motion
  - Small particles < 0.1μm



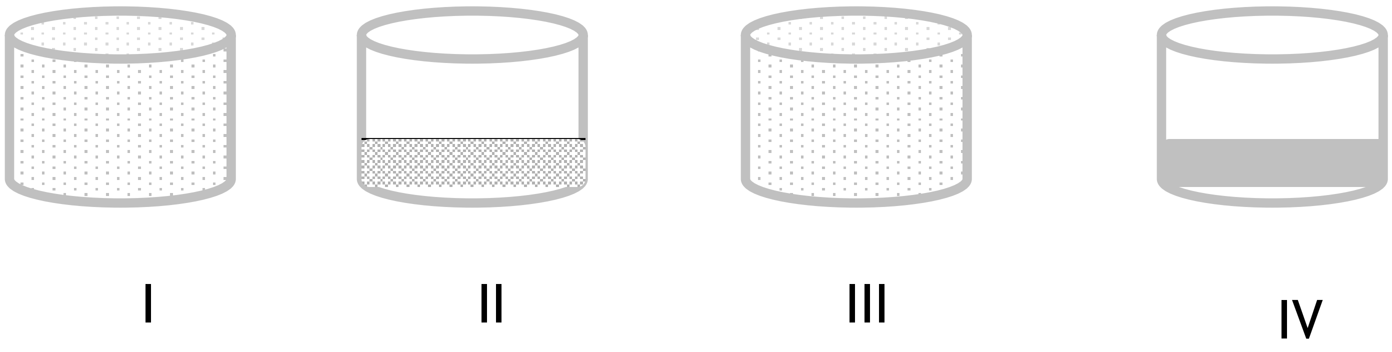
- Laminar and Turbulent Shear
  - mixing
  - Due to velocity gradient
  - Particles > 1μm
  - Fluid shear-different particles travel at different speed



- Differential settling
  - Important for larger particles
  - Gravitational forces
  - Larger particles settle faster
  - Different particle sizes
  - Particles > 80μm



# Coagulation-Flocculation

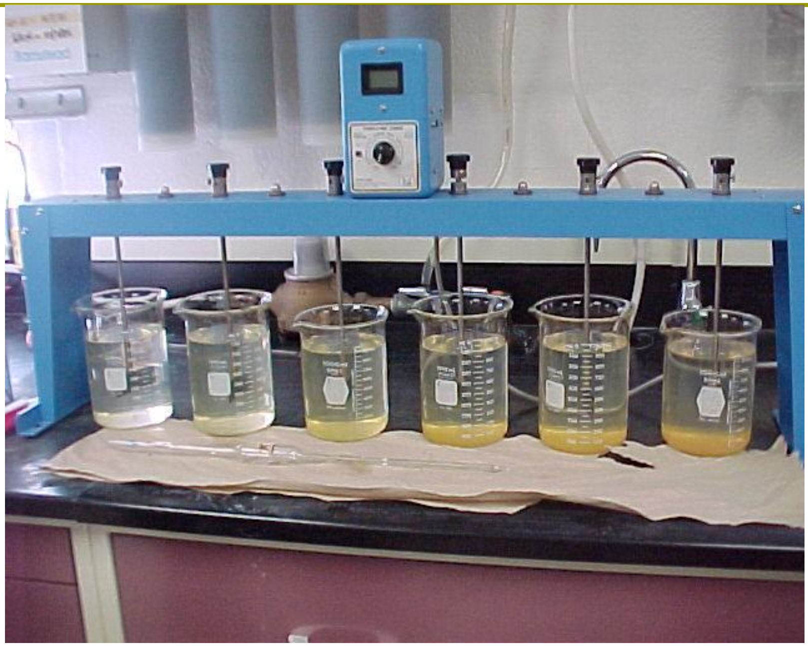



**Over dose problems??**

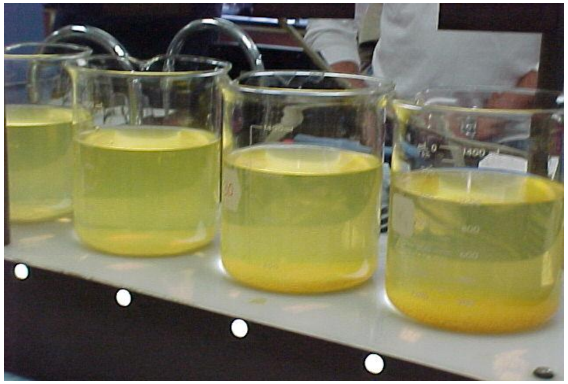
# Coagulation-Flocculation

Practical Approach

- Jar Test
  - Chemical addition
  - Rapid mix
  - Slow mix



- Measure
  - pH
  - Turbidity-suspended solid removal
  - DOC- NOM removal-UV 254nm
  - Residual dissolved coagulant concentration
  - Sludge volume
- Analyze
  - Optimum coagulant dose and pH



# Coagulation practice-Inorganic coagulant

- Inorganic Coagulant
  - Alum
  - Acidic-
  - consume OH as they hydrolyze

$$Al_2(SO_4)_3 \leftrightarrow 2Al^{+3} + 3SO_4^{-2}$$

$$Al^{+3} + 6H_2O \leftrightarrow Al(H_2O)_6^{+3}$$

$Al_2(SO_4)_3.14\ H_2O + 6HCO_3- \Leftrightarrow 2Al(OH)_3\downarrow + 6CO_2 + 14H_2O + 3SO_4^{-2}$

  - Ferric chloride

$$FeCl_3 \leftrightarrow Fe^{+3} + 3Cl^{-}$$

# Jar Test- Alkalinity

- QUIZ:

  Determine the required alkalinity to treat natural water with flow of 3000 L/d with 60 mg/L Alum? Weight of alkalinity per day?

$$Al_2(SO_4)_3.14\ H_2O + 6HCO_3^- \Leftrightarrow 2Al(OH)_3\downarrow + 6CO_2 + 14H_2O + 3SO_4^{-2}$$

# Jar Test- Alkalinity

- Example:

  Determine the required alkalinity to treat natural water with flow of 3000 L/d with 60 mg/L Alum? Weight of alkalinity per day?

$$Al_2(SO_4)_3.14\ H_2O + 6HCO_3^- \Leftrightarrow 2Al(OH)_3\downarrow + 6CO_2 + 14H_2O + 3SO_4^{-2}$$

# Alkalinity-Coagulation Relationships

- Addition metallic salts release Hydrogen ions
  - Hydrogen ions neutralize alkalinity
  - 1mg/L alum neutralize 0.5 mg/L alkalinity
- Low alkalinity must be buffered to maintain coagulation
  - lime $Ca(OH)_2$ or soda ash ($Na_2CO_3$)

# Coagulation-Flocculation

- For effective treatment must add
  - Lime
  - Sodium carbonate

# Coagulation Practice

- Quiz 2: High turbidity- low alkalinity
  - coagulant dosage
    a. High
    b. small
  - Mechanism
    a. Adsorption and charge neutralization
    b. Sweep floc
  - pH
    - a. affected
    - b. unaffected

# Coagulation Practice-Example

- Quiz 3: High turbidity- high alkalinity
  - coagulant dosage
    a. High
    b. small
  - Mechanism
    a. Adsorption and charge neutralization
    b. Sweep floc
  - pH
    - a. affected
    - b. unaffected

# Coagulation Practice-Example

- Quiz 4: Low turbidity- High alkalinity
  - coagulant dosage
    a. High
    b. small
  - Mechanism
    a. Adsorption and charge neutralization
    b. Sweep floc
  - pH
    - a. affected
    - b. unaffected

# Coagulation Practice-Example

- Quiz 5: Low turbidity- low alkalinity
  - coagulant dosage
    a. High
    b. small
  - Mechanism
    a. Adsorption and charge neutralization
    b. Sweep floc
  - pH
    - a. affected
    - b. unaffected

# Next Step

Sedimentation

# Filtration

- Remove fine suspended particles by passing through porous media

# Filtration- Filter media

Common materials for granular bed filters:

- sand
- anthracite coal
- garnet (silicates of Fe, Al, and Ca)

# Filtration

- Properties of granular material used in water filters

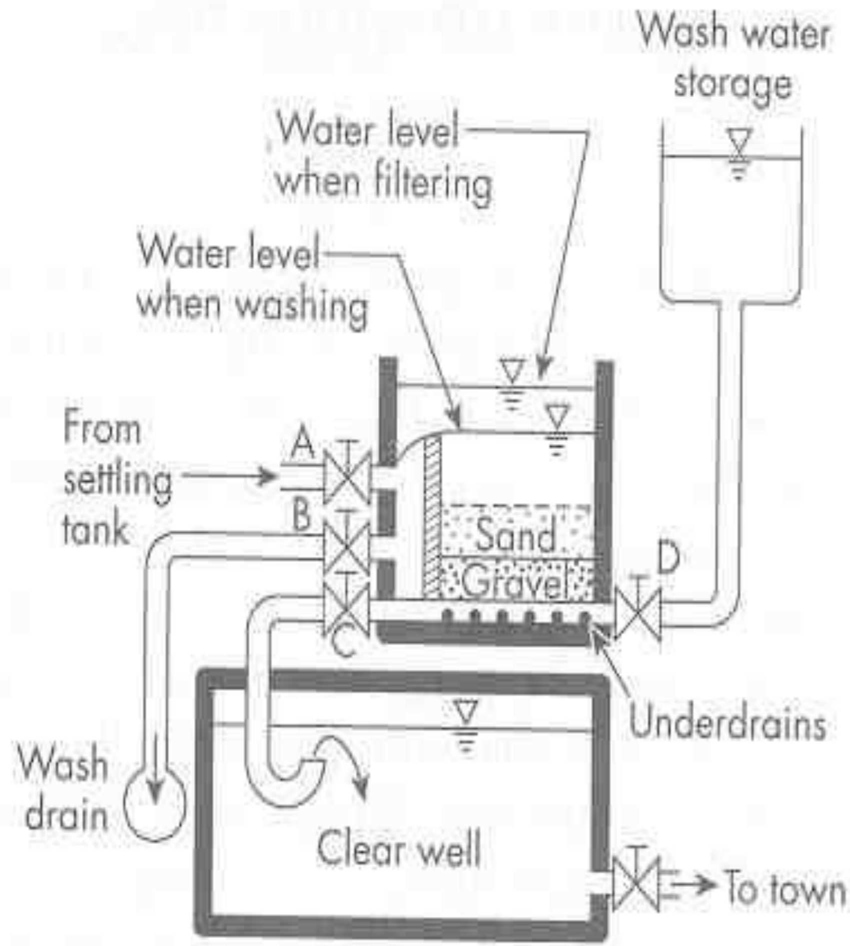
| Parameter | Silica sand | Anthracite | Garnet |
|---|---|---|---|
| Grain diameter | 0.45-0.55 | 0.9-1.1 | 0.2-0.3 |
| Grain density | 2.65 | 1.45-1.73 | 3.6-4.2 |
| Sphericity | 0.7-0.8 | 0.46-0.6 | 0.6 |
| Porosity | 0.42-0.47 | 0.56-0.6 | 0.45-0.55 |

# Filtration

- Rapid sand filters( most common)
  - Sieved sand on top of bed of gravel
  - Particles removed throughout depth of filter as collide with filter particles and stick small particles may be removed
  - Pretreatment to destabilize particles is essential
- Slow sand filters
  - Low filtration rate with the use of smaller sand
  - Filter sand is less uniform
  - Particles are removed on the surface of the filter( forming a mat of materials , called schmultzdecke)
  - Schmultzdecke forms a complex of biological community that degrade some organic compounds.
  - Pretreatment is not important

# Type of filtration

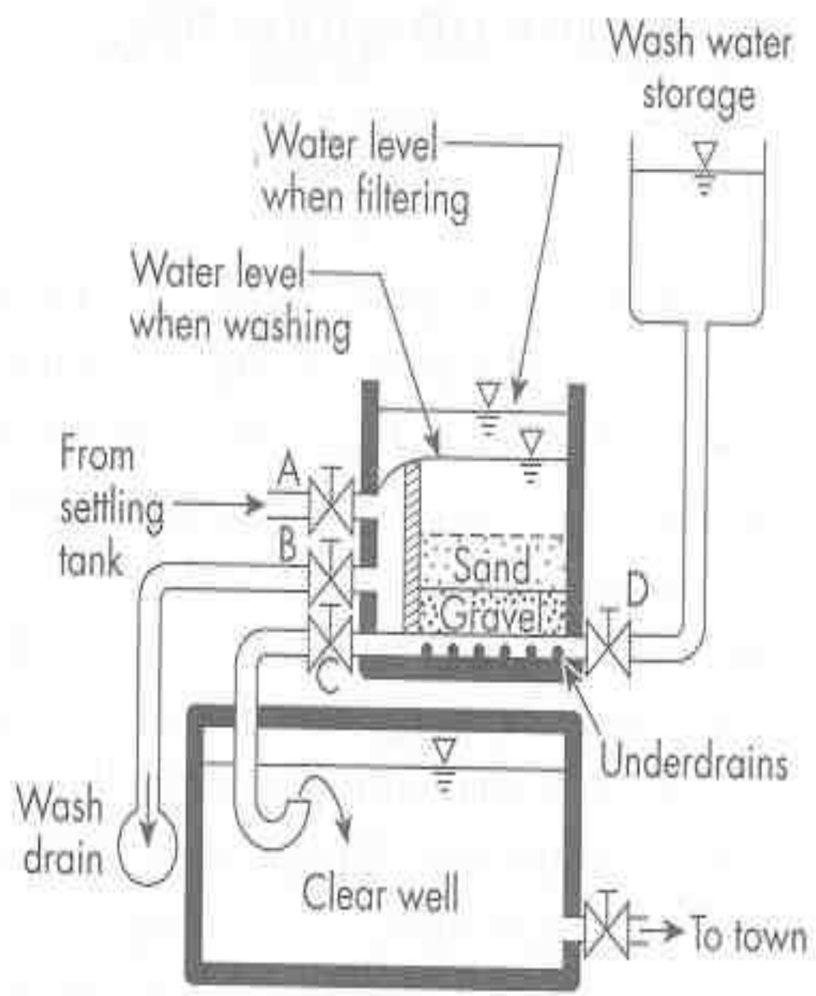
- How filter operates
  - Open valve A
  - Open Valve C
  - All other valves are closed



# Filter cleaning

- How filter is Backwashed
  - Open valve D
  - Open valve B
  - Close valves A and C

- Reverse direction of flow of water through the filter. Increase velocity until filter media particles become fluidized (suspended in flow). Particles bump against each other knocking the "dirt" off of them.
- When?
  - Head loss reaches the limit ( typically 2.4 to 3.0 m)
  - Below effluent acceptable level



# Filtration

The dual media filter

- The ideal, down flow filter would have larger diameter media near the top and smaller diameter media near the bottom.
- This would encourage depth filtration, and make use of the entire bed.

- After backwash, however, the larger particles settle faster.

A dual media filter circumvents this problem

- Low density, large diameter anthracite particles are near the top.
- Higher density, lower diameter sand is near the bottom.

# Filtration

- Mechanism in Rapid sand filter
  - Straining
  - Interception
  - Settling
  - Brownian motion
- Hard to quantify (empirical)
- Required destabilized colloids

# Filtration Design

- Key Elements
  - Hydraulics
  - Particle capture mechanism

- Parameters to be measure  during operation
  - The head loss across the filter
  - The turbidity of the effluent

# Filter hydraulic-Fluid flow in porous media-Darcy

- Head Loss: In filter-porous medium- lots of contact between water and the rough sand grains leads to significant pressure loss (head loss)

- Darcy’s law (1856)-flow through granular media
  - Reynolds number less than one

$$v = k\frac{dh}{dL} \qquad K = Hydraulic \quad conductivity\ velociy \quad unit$$

$$v = Dary's \qquad velocity$$

$dh/dl =$ Rate of change of pressure head with distance

- Filter hydraulic

  No mathematical descriptive of the porous material

# Filter hydraulic

- Carman-Kozeny

$$\frac{h}{L} = \frac{k_k \mu (1-\varepsilon)^2 S^2 v}{\rho_w g \varepsilon^3} \qquad valid \quad N_R < 6 \quad N_R = \frac{d_p * Q / A_s * \rho}{\mu}$$

where:

h = head loss
L= filter bed length
k = Kozeny coefficient, unitless≈5
v = superficial velocity ($Q/A_s$)
ρ = fluid density
μ = fluid viscosity
S= specific surface area of the filter grain (surface area per volume), 1/m
ε=Filter Porosity, dimensionless
$A_s$ =horizontal surface area

**For uniform granular material**

$$S = \frac{6}{\psi d}$$

# Filter hydraulic

Quiz:

A water treatment plant is being designed to supply $1 m^3/s$ of water for the nearby community. If sand filter is used, calculate the minimum surface area of the filter necessary to provide treated water at this rate

| | |
|---|---|
| Head loss =1m | Length of the filter= 0.75 m |
| Sand Sphericity $\Psi$ = 0.8 | Porocity $\varepsilon$ = 0.4 |
| $\rho$ = 998 $g/m^3$ | $\mu$ = 0.01 g/cm/s |
| K=5 | Sand grain diameter=0.5mm |

# Example

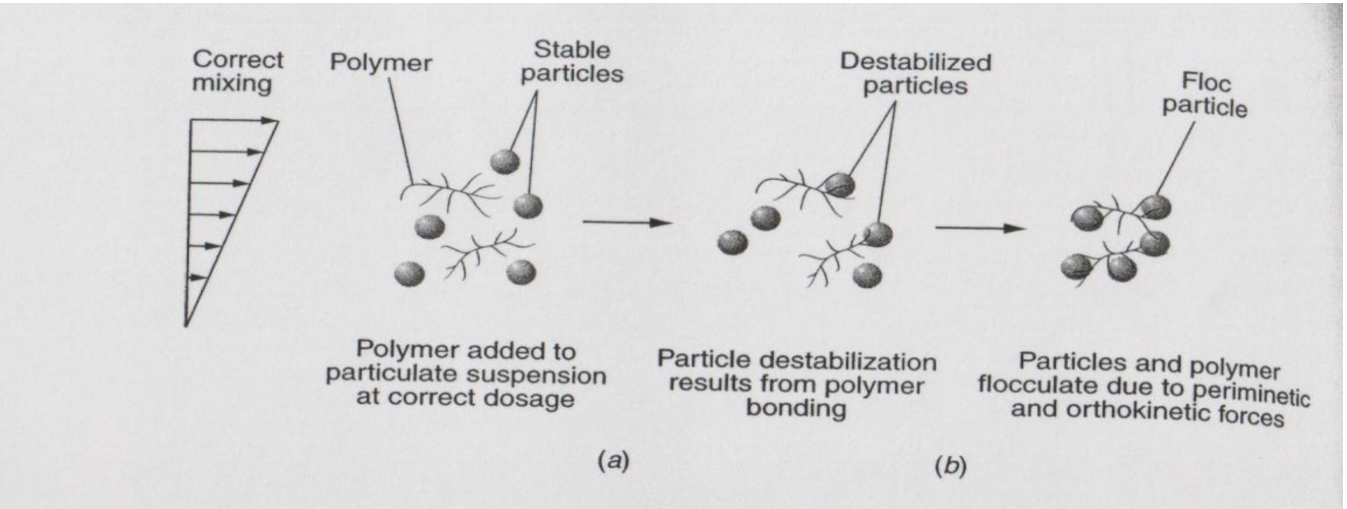
# Next

- Disinfection

# Coagulation mechanism

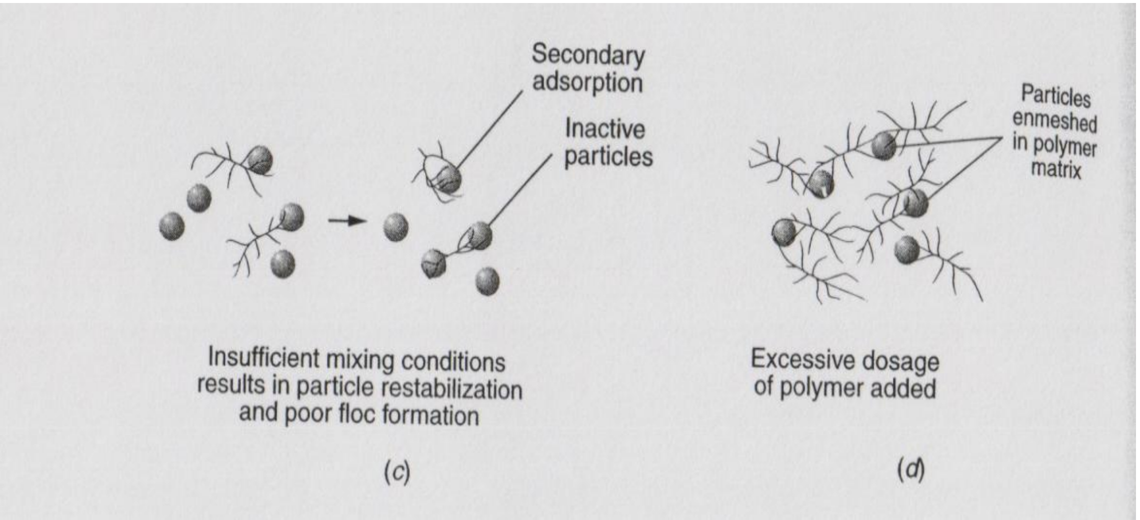
- Adsorption and inter particle bridging
  - Polymer adsorbs to several different colloids bridging them together
  - Occur in conjunction with charge neutralization
  - Higher molecular weight

- Reaction mechanism for polymer:



# Coagulation mechanism

## Reaction mechanism for polymer



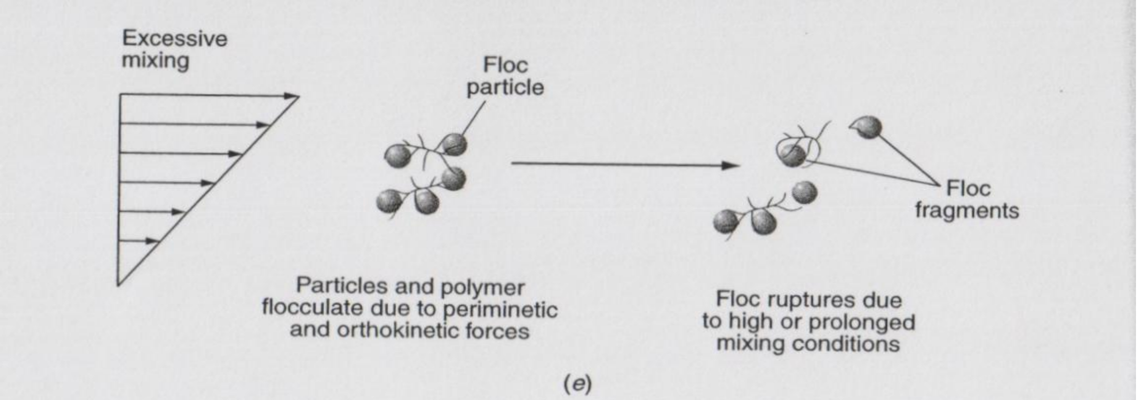




**Figure 9-10**
Schematic representation of the bridging model for the destabilization of diuturnal particles by polymers. (Adapted from O'Melia, 1972.)

# Coagulation practice-Inorganic Coagulant

- Inorganic Coagulant

Aquo Al ion $Al(H_2O)_6^{+3}$

$$\updownarrow \quad \rightarrow \quad H^+$$

Mononuclear species $Al(OH)(H_2O)_5^{+2}$

$$\updownarrow \quad \rightarrow \quad H^+$$

Polynuclear species $Al_3O_4(OH)_{24}^{+7}$

$$\updownarrow \quad \rightarrow \quad H^+$$

Precipitate $Al(OH)_{3(s)}$

$$\updownarrow \quad \rightarrow \quad H^+$$

Aluminate ion $Al(OH)_4^-$

# Electrical double layer