Physical/Chemical Process Fundamentals

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OUTLINE

- Properties of turbidity and organic matter
- Mechanisms of coagulation, coagulant chemicals and jar testing
- Conventional treatment technologies
- Enhanced clarification technologies
- Filtration
- Softening
**PARTICLE SIZES**

<table>
<thead>
<tr>
<th>Size, μm</th>
<th>Ionic</th>
<th>Molecular</th>
<th>Macromolecular</th>
<th>Microparticle</th>
<th>Macroparticle</th>
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**COLLOIDAL BEHAVIOR**

**Colloids:** particles whose size is too small to allow gravity to overcome Brownian motion - clay particles, organisms

**Particle characteristics:**

**PARTICLE SIZE**

**NUMBER & DISTRIBUTION**

**SHAPE**

**PARTICLE-SOLVENT INTERACTIONS**
• Zeta potential = charge at the slipping plane
Coagulation can occur when the charge on the surface of the colloid is altered so the net resultant force is attractive.

Organic Matter
- Decomposition products of vegetal matter and biological organisms
- Characterized by TOC
- Structure determines ease of removal
- Oxidize to change structure
- Adsorb onto PAC or GAC
- Coagulate
**HUMIC ACID**

- Carboxylic Acid
- Double Bond

**COAGULATION**

- Destabilizes small suspended and colloidal particles
- Adsorbs or reacts portions of the colloidal and dissolved NOM to particles
- Creates flocculant particles
Mechanisms of COAGULATION

**Adsorption and Charge Neutralization**
- Reduce the magnitude of the repulsive force by adding a substance of opposite charge to neutralize the surface charge
- High turbidity waters

**Precipitation and Enmeshment** (Sweep Floc)
- Various salts (alum, ferric chloride, magnesium hydroxide) added to a suspension in high enough concentrations to form precipitates into which colloidal particles become enmeshed as the precipitates settle.
- Low turbidity water

**Adsorption and Interparticle Bridging**
- Organic molecules (polymers) with a large molecular size with multiple electrical charges along the polymer
- Adsorb to multiple particles in suspension, thereby forming a bridge between the particles causing a larger collection of particles to form

**Inorganic Coagulants**

**Aluminum**
- aluminum sulfate (alum) \( \text{Al}_2(\text{SO}_4)_3 \cdot 14.3\text{H}_2\text{O} \)
- sodium aluminate \( \text{NaAlO}_2 \)

**Iron**
- ferric chloride \( \text{FeCl}_3 \)
- ferrous sulfate \( \text{FeSO}_4 \cdot 7\text{H}_2\text{O} \)
- ferric sulfate \( \text{Fe}_2(\text{SO}_4)_3 \)

**Pre-hydrolysed Metal Salts**
- polyaluminum chloride (PACl)
- aluminum chlorohydrate (ACH)
POLYMERS

- Dry, liquid
- Non-ionic (no charge)
- Cationic (positive charge - use for negatively charged particles)
- Anionic (negative charge - use for positively charged particles)
- Wide range of sizes (molecular weights)

Jar Test Apparatus
JAR TESTING

- Optimize dosage or select chemical
- Range of dosages tested
- Rapid mix, flocculation and settling conditions similar to treatment facility
- Settled supernate is sampled and analyzed for parameter of interest
- Select dosage exhibiting minimum turbidity
JAR TEST RESULTS

- Removed by adsorption, co-precipitation into the coagulant
- Frequently need higher dosages than those required for turbidity removal
- pH sensitive

ORGANICS (TOC REMOVAL)
## Treatment Technologies

### TURBIDITY

<table>
<thead>
<tr>
<th>Conventional Coagulation Plant</th>
<th>Enhanced Settling</th>
<th>Softening</th>
<th>Membrane Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rapid mix / flocculation / sedimentation / filtration</td>
<td>• Tube/plate settlers</td>
<td>• High pH lime softening</td>
<td>• Micro/ultra filters</td>
</tr>
<tr>
<td></td>
<td>• Sand-ballasted settling/filtration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BACK MIX REACTOR
IN-LINE RAPID MIXER

FLOCCULATION
# Flocculator Operations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixing intensity</td>
<td>• $G = 15-75$ /sec</td>
</tr>
<tr>
<td>Detention time</td>
<td>• 20-40 minutes</td>
</tr>
<tr>
<td>Water Depth</td>
<td>• 10 – 15 ft</td>
</tr>
<tr>
<td>Stages</td>
<td>• 2-6 stages, (commonly 3-4 stages)</td>
</tr>
<tr>
<td>Temperature effect</td>
<td>• Changes viscosity of water – more energy at lower temps</td>
</tr>
</tbody>
</table>

- Desired plug flow

- Changes viscosity of water – more energy at lower temps

- Temperature effect

- Mixing intensity

- Detention time

- Water Depth

- Stages

- Temperature effect
Settling
“IDEAL” CLARIFIER

SETTLING (CLARIFICATION)
SURFACE OVERFLOW RATE

- Settling velocity of slowest settling particle 100% removed.

\[
500 \frac{\text{gal}}{d - \text{ft}^2} \times \frac{d}{1440 \text{ min}} \times \frac{ft^3}{7.48 \text{ gal}} \times \frac{12 \text{ in.}}{ft} = 0.56 \text{ in./min}
\]

Having a surface overflow rate of 500 gpd/ft² should result in 100% removal of those particles that settle at a rate of 0.5 inch/minute.

**Conventional ALUM COAGULATION**

<table>
<thead>
<tr>
<th>Application</th>
<th>Loading Rate, gpd/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity removal</td>
<td>800-1200</td>
</tr>
<tr>
<td>Color and taste removal</td>
<td>600-1000</td>
</tr>
<tr>
<td>High Algae Content</td>
<td>500-800</td>
</tr>
</tbody>
</table>

Source: AWWA – Water Treatment Plant Design 4th Ed.
Chemistry Affects Settling

**Predominantly calcium carbonate precipitates**: negatively charged particles, may need a cationic polymer to flocculate well

**Higher pH causes magnesium hydroxide precipitates**: positively charged particles interact with negatively charged calcium carbonate particles, providing flocculation

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**Lime Dosage**

**TUBE SETTLERS**

- Inclined tubes (60 degrees to horizontal)
- 0.4-0.8 gpm/ft² of tube surface area
- 1,500-4,500 gpd/ft² loading rate
- Space below the tubes to allow sludge settling and removal
- 2-3 ft depth above tubes to the effluent launders
PLATE SETTLERS

- 0.3-0.7 gpm/ft² of plate area
- Basin loadings of 3000-8000 gpd/ft²
BALLASTED FLOC

- Actiflo – US Filter-Krueger
- Coagulated floc attached to sand using a polymer
- Coagulation, injection, maturation, settling
- Typically 20,000-28,000 gpd/ft² loading rate in the clarifier
Optimized Actiflo

- Marbling in Maturation
- Low Turbidity Effluent
- Proper Sand Balance
**Filtration**

- Remove suspended matter from water by passing it through a porous media
- Try to simulate filtration by soil
- Suspended matter may be precipitates, flocs, or microorganisms
  - Turbidity < 0.3 NTU to meet requirement of IESWTR
  - Iron < 0.3 mg/L
  - Manganese < 0.05 mg/L
  - Hardness precipitates

**Types of Filters**

**Gravity**
- Slow-sand 0.05 gpm/ft²
- Rapid-sand 2-4 gpm/ft²
- High-rate 4-10 gpm/ft²

**Pressure**
- Sand or multimedia
GRAVITY FILTERS

- Wash Water Trough
- Anthracite Sand
- Support Gravel
- Flow During Backwash (Water to Waste)
- Flow During Filtration (Raw Water)
- Universal Air/Water Underdrain
- Air Distribution Manifold
- Collection Flume
- Backwash Water
- Filtered Water
- Air Scour Supply

Images of gravity filter installations are also shown in the document.
BACKWASHING PROCESS
Individual Filter TURBIDITY PROFILE

 FILTER TO WASTE

- Filtered water after backwash contains higher turbidity
- Discard this water to prevent transmission of organisms into the clearwell
MEMBRANE SYSTEMS
LIME SOFTENING

- Hardness (Ca/Mg) removal
- Organics removal (enhanced softening) optimized at pH > 10.5-11
- Calcium is precipitated as CaCO$_3$
  \[ \text{CaCO}_3 \downarrow \leftrightarrow \text{Ca}^{2+} + \text{CO}_3^{2-} \]
- Magnesium is precipitated as Mg(OH)$_2$
  \[ \text{Mg(OH)}_2 \downarrow \leftrightarrow \text{Mg}^{2+} + 2\text{OH}^- \]

MECHANISMS OF REMOVAL

- Lime
  - Raises the pH - create CO$_3^{2-}$ from HCO$_3^-$ in stoichiometric equations,
    \[ \text{HCO}_3^- + \text{OH}^- \rightarrow \text{CO}_3^{2-} + \text{H}_2\text{O} \]
  - Provides OH$^-$ for Mg(OH)$_2$ precipitate
- Soda ash
  - Provides CO$_3^{2-}$ when natural alkalinity is short (precipitate non-carbonate hardness)
- Turbidity and organics (negatively charged) are incorporated into the floc
  - Works best at pH>10.5
Finding the SWEET SPOT

River Water Jar Test 2-14-2014

Solids Contact (Upflow) CLARIFIERS

• Surface Loading Rates: 720 – 2200 gpd/ft² for color and turbidity removal: softening systems designed for 2-4 times the settling rate in a conventional basin
### OTHER PROCESSES

<table>
<thead>
<tr>
<th>Category</th>
<th>Processes</th>
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</thead>
<tbody>
<tr>
<td><strong>Oxidation</strong></td>
<td>Ozone, permanganate, advanced oxidation</td>
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<tr>
<td><strong>Adsorption</strong></td>
<td>PAC, GAC</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td>Filtration, BAC</td>
</tr>
<tr>
<td><strong>Membranes</strong></td>
<td>MF/UF, NF/RO</td>
</tr>
</tbody>
</table>