Advanced Polymer Mixing for Improved Dewatering

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Why Polymer?

Helping particles settle faster

Improving liquid/solid separation
## Settling Rates

<table>
<thead>
<tr>
<th>Diameter of Particle, mm</th>
<th>Order of Size</th>
<th>Total Surface Area</th>
<th>Time Required to Settle</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>Gravel</td>
<td>0.487 sq in</td>
<td>0.3 sec</td>
</tr>
<tr>
<td>1.0</td>
<td>Coarse Sand</td>
<td>4.87 sq in</td>
<td>3.0 sec</td>
</tr>
<tr>
<td>0.1</td>
<td>Fine Sand</td>
<td>48.7 sq in</td>
<td>38 sec</td>
</tr>
<tr>
<td>0.01</td>
<td>Silt</td>
<td>3.38 sq ft</td>
<td>33 min</td>
</tr>
<tr>
<td>0.001</td>
<td>Bacteria</td>
<td>33.8 sq ft</td>
<td>55 hr</td>
</tr>
<tr>
<td>0.0001</td>
<td>Colloidal particles</td>
<td>3.8 sq yd</td>
<td>230 days</td>
</tr>
<tr>
<td>0.00001</td>
<td>Colloidal particles</td>
<td>0.7 acre</td>
<td>6.3 yrs</td>
</tr>
<tr>
<td>0.000001</td>
<td>Color particles</td>
<td>7.0 acre</td>
<td>63 yrs</td>
</tr>
</tbody>
</table>
Some Applications

Clarifiers
Primary Coagulation
Plate & Frame Press
Rotary Drum Thickener
Belt Press
Drying Beds
Gravity Belt Thickener
Centrifuges
Paper Machines
Mining & Metal Processing
Paint Booths
Enhanced Oil Recovery
## Inorganic Salts

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Formula</th>
<th>Equivalent weight</th>
<th>pH at 1%</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>Al₂(SO₄)₃ * 14H₂O</td>
<td>100</td>
<td>3.4</td>
<td>Lump – 175 Al₂O₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Liquid – 8.5% Al₂O₃</td>
</tr>
<tr>
<td>Lime</td>
<td>Ca(OH)₂</td>
<td>40</td>
<td>12</td>
<td>Lump – as CaO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Powder – 93-95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Slurry – 15-20%</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>FeCl₃ * 6H₂O</td>
<td>91</td>
<td>3-4</td>
<td>Lump – 20% Fe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Liquid – 20% Fe</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>Fe₂SO₄ * 3H₂O</td>
<td>51.5</td>
<td>3-4</td>
<td>Granular – 18.5% Fe</td>
</tr>
<tr>
<td>Copperas</td>
<td>FeSO₄ * 7H₂O</td>
<td>139</td>
<td>3 – 4</td>
<td>Granular – 20% Fe</td>
</tr>
<tr>
<td>Sodium aluminate</td>
<td>Na₂Al₂O₄</td>
<td>100</td>
<td>11 – 12</td>
<td>Flake – 46% Al₂O₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Liquid – 25% Al₂O₃</td>
</tr>
</tbody>
</table>
Inorganic Salts

Advantages

- Low Cost

Disadvantages

- pH dependent
- Typically higher dosage and increased sludge volumes
- No reduction of organic residuals
- Weak flocs
Synthetic Organic Polymers

Advantages

- Strong Stable Floc
- Improved dewatering
- No additional sludge volume
- Effective over wide pH range
- Can reduce organic molecules

Disadvantages

- Slippery – safety hazard
- Needs proper mixing & activation
- Handling and proper application effects performance
Molecular Weight

Low - Coagulant

High - Flocculant
Polymer Charges

Non-ionic = no charge

Anionic = negative (-) charge

Cationic = positive (+) charge
Charge Density
What are the different Forms of Polymers?

- Coagulant
- Mannich
- Emulsion/Dispersion
- Dry
Forms Of Polymers

Coagulant (Solution Polymers):
- 10% - 50% active
- Low molecular weight 5K - 200K
- Appearance - clear homogeneous liquid
- Package - Pails, Drums, Bins, Bulk
- Easy to dilute
- “Neat” product easy to pump
- Susceptible to Freeze
- Charge - cationic, anionic
Forms Of Polymers

MANNICH - Solution

- Flocculant
- 4 - 6% active
- Low molecular weight segments 5K - 200K
- Appearance - clear to amber liquid
- Package – Bulk
- Can Freeze
- “Viscous” can be hard to pump
- Viscosity temperature dependent
- Fumes are “unpleasant”
- Charge - cationic only
Forms Of Polymers

Emulsions/Dispersions:

- 25 - 55% active
- Appearance - white liquid
- Medium to High molecular weight - 5M - 10M
- Appearance - clear homogeneous liquid
- Package - Pails, Drums, Bins, Bulk
- “Neat” product easy to pump but!!
- Needs “Activation”
- Susceptible to Freeze
- Will settle in “neat” form
- Charge - cationic, anionic, non-ionic
Forms Of Polymers

Dry Polymers:
- 90% - 95% active
- All molecular weights to 20M+
- Appearance - powder, pellets, granules, beads
- Package - bags, bulk bags
- Must be wetted
- Dusting is safety concern
- Shelf life in years
- Charge - cationic, anionic, non-ionic
High Molecular Weight Polymers

Solution Polymer (Mannich)
- Cationic only
- Molecular weight: up to 10 M
- 4 - 6% active
- Cost: low
- Typical dilution: 5% for dewatering only

Emulsion Polymer
- Cationic, anionic, non-ionic
- Molecular weight: up to 10 M (cationic), up to 20 M (anionic, non-ionic)
- 30 - 60% active
- Polymer gel size: 0.1 to 5 µm
- Cost: very high
- Typical dilution: 0.25% for clarification, 0.5% for dewatering

Dry Polymer
- Cationic, anionic, non-ionic
- Molecular weight: up to 10 M (cationic), up to 20 M (anionic, non-ionic)
- > 95% active
- Polymer particle size: 0.1 to 1 mm
- Cost: high
- Typical dilution: 0.1% for clarification, 0.25% for dewatering
Polymers (Polyelectrolytes)

- How they work
- How can we characterize them
- How to make them work
Selection of Polymers

- Type Of Polymer
- Molecular Weight
- Charge Density
- % Active Content
- Bench Test Performance Evaluations
Coagulation and Flocculation

Coagulation

- **Enmeshment** (Sweep Coagulation)
  - Clay suspension + Ferric chloride

Flocculation

- **Polymer Bridging**
  - Clay suspension + Ferric chloride + Polymer
Jar Tests
Emulsion Polymers

- Anionic, Cationic, Nonionic
- Flocculant
- 25% to 55% active
- Polymer gel size 0.1 to 5 um
Storage of Emulsion Polymer

- Separation (stratification)
  - Drum (Tote) Mixer
  - Recirculation Pump

- Moisture Intrusion
  - Drum (Tank) Dryer

Separated Oil

Density: ~ 1.02 g/ml
Viscosity: 400 - 1000 cP

Viscosity of polymer solution
0.25%: 100 - 200 cP
0.50%: 400 - 800 cp
1.00%: 2000 - 4000 cP

Settled Out Polymer Gels
Methods Of Preparation / Activation

- In-Line Activation
- Batch Tank
Preparation / Activation

- Moment Of Initial Wetting
- Agglomeration / Fragility
- Rate Of Hydration
- Charge Site Exposure
Polymer Activation (Dissolution)

Initial Wetting (Inversion)
- Sticky layer formed
- High-Shear Mixing Required

Dissolution
- “Reptation” - de Gennes (1971)
- Low-Shear Mixing Required
How Complex Is A Polymer Structure?

If MW is 10 million
350,000 molecules in a gel
One molecule has 150,000 monomers

2.5 microns = 0.0001”
Rate Of Hydration (The Science)

With good dispersion at Moment of Initial Wetting a 1 micron radii polymer particle can fully hydrate in 1 minute

swells ~ 6-7 times
Rate Of Hydration (Reality)

Without good dispersion agglomerations are formed
10 micron agglomeration will fully hydrate in ___ min(s)
Rate Of Hydration (Attempt to Correct)

Without good dispersion agglomerations are formed

10 micron agglomeration will fully hydrate in 100 min(s)

Time increases by the square of the increase in the radius (10 squared)
Characteristics of Polymer Activation

- **Initial wetting stage:**
  - negligible fragility
  - very high shear mixing
  - minimize fisheye formation

- **Dissolution stage:**
  - negligible agglomerability
  - low shear mixing
  - minimize polymer fracture
Effective Polymer Preparation

- The most important factor determining the proper activation of polymer is proper application of energy.
- The energy needs to be adjustable to suit the polymer selection and process application.
Polymer Activation Factors

- High TDS makeup water
- Low temperature makeup water
- High molecular weight polymer
- Low charge density
- High or low surfactant
- With anionics, low pH and/or high hardness (ideal 7-9)
- With cationics, high pH makeup water (ideal 6-8)
- Chlorine levels
Recommended Dilution Water Quality

**Ionic strength (Hardness):** multi-valent ions; adverse effect
- Soft water helps polymer molecules fully-extend faster
- Hardness over 400 ppm may need softener

**Oxidizer (chlorine):** detrimental to polymer chains
- Maintain less than 3 ppm

**Temperature:** higher temperature, better polymer activation
- In-line water heater for water lower than 40 °F
- Water over 100 °F may damage polymer chains

**Suspended solids:** strainer recommended if > 10 ppm

**pH:** negligible effect within pH 3 - 10
Polymer Backbone – Carbon-Carbon Bonds
How Fragile is It?

- One gram of free falling water will rupture 1 million carbon-carbon bonds.

- Proper application of energy is critical
Characteristics of Polymer Dissolution

- Fragility
- Agglomeration

(time)
Activation Measures

Polymer Activation Research Credit of Yong H. Kim Ph.D.
Charge Site Exposure

Figure 3
Polymer Activation vs Aging Time

Flow Rate: 12 GPH
Emulsion Polymer - F @ 1.0%

Legend
- Continuous System
- Batch System (S-2)

CHARGE DENSITY (meq/l)

TIME INTERVAL (min)

0 20 40 60 80 100 120
The “Art” of Aging

- Aging is a **Solution to a Problem** not a method or the goal of polymer activation
- Aging is always required of all improperly mixed polymer solutions
- Aging is a **attempt** to gain total polymer activation
- Too much aging is detrimental to a properly mixed polymer
Mixing Zones

- Conventional Mixing
Uniform Energy

Fig. 4. Spatial distribution of the ratio of local dissipation rate to mean dissipation rate (Okamoto et al., 1981).
Uniform Energy

As the tank is made smaller, the energy becomes uniform.
Staged Energy

A uniform but decreasing energy dissipation can be created with various mixing zones.
Mixing Chamber Energy Profile

Zone 1

Zone 2

Zone 3

Fragility

Agglomeration

(time)
Greeley CO Wastewater Treatment Plant

- Design capacity: 14.7 MGD
- AMSA - Platinum Award: only 15 plants in US (2000)
- EPA - National First-Place for Industrial Pretreatment Program (2000)
- Xcel Energy Custom Efficiency Achievement Award (2011)
Problem and Solution to Poor Solids Recovery

- Problem in dewatering process (2010)
  - Struggled to make 15% - 16% dry solids
  - Polymer usage jumped up to 80 lb/d.t.s.
- Existing polymer preparation system
  - 500 gal batch tank with high-speed impeller
  - 30 minute aging before feeding to centrifuge
- New polymer equipment trials (2012)
  - Two different in-line polymer mix/feed equipment
  - Three-week trial for each
  - ProMinent ProMix unit was selected
- Improved performance
  - ProMix was installed permanently in May 2012
  - Cake solids consistently 19% - 20%
  - Polymer usage down to 30 - 35 lb/d.t.s.
Polymer Mixing Equipment for Centrifuge

Dewatering centrifuge, 6000 rpm
2% TS sludge $\rightarrow$ 20% TS cake

ProMix to feed polymer solution to centrifuge
Other Factors Influencing Optimization

- Discharge Piping
  - Minimize Fluid Velocity
  - Eliminate High Shear Pumping Systems
- Multiple Points Of Injection
- Evaluate System Piping Downstream Of Polymer Injection
- Determine Optimal Feed Concentrations
Conclusions

- Survey your system needs for improvement
- Evaluate costs for improvement vs. savings as result of the improvement
- Be aware of new technologies & strategies that will help you be more efficient
Polymer Process Improvements

- Higher dry solids
- Lower sludge disposal costs
- Lower energy costs
- Lower operational costs
- Longer filter runs
- Higher clarity
- Less sludge returns
- Lower chemical costs
- Less labor
Any Questions?

- Thank you.