How to Maximize the Value of Polymers in Wastewater Treatment Processes

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Coagulation and Flocculation

Coagulation
- Double-layer compression (charge neutralization)
- Enmeshment (sweep coagulation)
  - Clay suspension + Ferric chloride

Flocculation
- Polymer Bridging
  - Clay suspension + Ferric chloride + Polymer (0.1 - 1 ppm)
Flocculation - Bridging by Polymer Molecules

Extended cationic polymer molecule attracts negatively-charged suspended particles
Structure of Polymer

• Polymer Flocculant, Linear Polymer, Polyelectrolyte
• Chained Structure by Repetition of Monomers

\[ \ldots - \text{CH}_2 - \text{CH} - [\text{CH}_2 - \text{CH}]_n - \text{CH}_2 - \text{CH} - \ldots \]

\[
\begin{array}{ccc}
& \text{CO} & \text{CO} & \text{CO} \\
\text{NH}_2 & \text{NH}_2 & \text{NH}_2 \\
\end{array}
\]

Most polymers in water industry are acrylamide-based.

If molecular weight of polymer is 10 million, the number of monomers in one polymer molecule, “degree of polymerization”

\[ n = \frac{10,000,000}{71} \]
\[ = 140,850 \]

(mol. wt. of monomer, acrylamide = 71)
Emulsion Polymer - 40% active

$d = 0.1$ to $2 \, \mu m$

- Hydrocarbon Oil: 30%
- Polymer Gel: Polymer 40%
- Water: 30%
- Stabilizing surfactant
- Inverting (breaker) surfactant

To maximize the value of Inverting Surfactant:
* 0.75% - 1.0% primary mixing
* 0.25% - 0.5% secondary mixing (dilution)

* AWWA Standard for Polyacrylamide (ANSI-AWWA B453-96), 10 - 11, 1996
How to Maximize the Value of Inverting Surfactant?

Primary mixing at high % + Secondary mixing at feed %

Better Design

Primary Mixing

Polymer 1 gph

Water 100 gph

1.0%

Secondary Mixing

Water 100 gph

0.5% solution

Primary Mixing

Polymer 1 gph

Water 200 gph

0.5%

0.5% solution
Storage of Emulsion Polymer

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

- **Settled Out Polymer Gels**

- **Separated Oil**

- **Moisture Intrusion**
  - Drum (Tank) Dryer

* Image of a drum showing separation and moisture intrusion.
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

*David Oerke (CH2M), et al., 2014 Biosolids Conf. - 20% less polymer with warm water, 40% more polymer with 140°F sludge*
Effect of Chlorine (Oxidizing Chemical)

Oxidizing chemicals break down polymer chains

![Graph showing the effect of chlorine on viscosity]

- **Viscosity** in cP decreases as **Cl₂ ppm** increases.
- The viscosity decreases from approximately 1200 cP at 0 ppm Cl₂ to around 100 cP at 10 ppm Cl₂.
Polymer Activation (Dissolution)

1. Initial Wetting (Inversion)
   Sticky layer formed
   High-energy Mixing Required

2. Dissolution
   “Reptation” by de Gennes (1971)*
   Low-energy Mixing Required

Mixing Effect on Polymer Activation

Viscosity of polymer solution
(prepared in 600 mL beakers)
- Beakers 1, 2: one-stage mixing
- Beaker 3: two-stage mixing

Two-stage mixing resulted in polymer solution of much better quality
* High energy first: prevent fisheye formation
* Low energy followed: minimize polymer damage
Development of Two-stage Mixer

1-stage mixer

2-stage mixer

G-value, mean shear rate (sec⁻¹)

1,700

1,100

4,000
Mixing Effect on Polymer Activation

Two-stage mixing $\rightarrow$ significant increase in polymer solution viscosity

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Mixing unit</th>
<th>Conc. %</th>
<th>Viscosity cP</th>
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<tbody>
<tr>
<td>Anionic</td>
<td>1-stage</td>
<td>0.50</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>2-stage</td>
<td></td>
<td>310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(27%↑)</td>
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<tr>
<td>Cationic</td>
<td>1-stage</td>
<td>0.50</td>
<td>427</td>
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<tr>
<td></td>
<td>2-stage</td>
<td></td>
<td>523</td>
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<td></td>
<td></td>
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<td>(18%↑)</td>
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<tr>
<td>Nonionic</td>
<td>1-stage</td>
<td>0.50</td>
<td>156</td>
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<tr>
<td></td>
<td>2-stage</td>
<td></td>
<td>178</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>(12%↑)</td>
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</tbody>
</table>
PolyBlend Dry Polymer System

High Energy Mixing

\[ G = 15,000 \text{ /sec} \]
\[ (3,450 \text{ rpm, } <0.5 \text{ sec}) \]

Low Energy Mixing

\[ (115 \text{ rpm, 20 min}) \]
\[ (0.5\% - 0.75\%) \]

Post-dilution

\[ (0.1\% - 0.2\%) \]

DD4

DP800

Final Feed Skid
Dry Disperser (DD4) for Initial Wetting

Very High-Intensity Mixing for Short Time

\[ G = 15,000 \text{ /sec} \]
\[ @ 3,450 \text{ rpm} \]
\[ \text{for < 0.5 sec} \]

Disperses Individual Polymer Particles

* No Fisheye Formation
* Shorter Mixing Time in Next Stage
Mixing Tank for Dissolution of Dry Polymer

Patented Hollow-Wing Impeller
- No Weissenberg Effect

Large Impeller, \( \frac{d}{D} > 0.7 \)
- Uniform Mixing Energy

Low RPM, 60 - 115 rpm
- Low-intensity Mixing
- Minimize Damage to Polymer Chain

Square Tank Design
- No Wessenberg Effect
- No Baffles Needed, No Dead Zone

Shorter Mixing Time – Due to DD4
- 20 Minutes for Cationic Polymer
- 30 Minutes for Anionic Polymer
- Minimize Damage to Polymer Chain
Fairfield-Suisan, CA - Sewer District

- Solano County, CA, 40 miles North San Francisco
- Design capacity: 24 MGD
- Population served: 135,000
- Tertiary treatment/ UV disinfection
- Polymer use for dewatering (screw press) and thickening (GBT)

- Problems with existing polymer system
  - Struggled to make proper polymer solution
  - Polymer performance inconsistent
  - Frequent maintenance issues
Pilot Testing with Two Polymer Mix Equipment

Existing polymer system
• Initial wetting: educator-type hydraulic mixing
• Mixing: two (2) > 3,000 gal mix/age tanks

UGSI dry polymer system
• Initial wetting: high-energy mechanical mixing
• Mixing: two (2) 360 gal mix tanks
Fairfield-Suisan SD – Pilot Test Results

- **Dewatering by Screw Press** (3/21 – 4/21)
  - Less polymer consumption
    - 1200 lb super sack lasted from 3.4 to 4.4 days
    - Daily usage from 359 lbs to 278 lbs (23% less)
    - $4,300/month polymer savings
  - Better cake solids
    - 14% ~ 16% to average 16.4%

- **Thickening by GBT** (4/24 - 5/23)
  - Less polymer consumption
    - Daily usage from 40 lbs to 17.5 lbs (56% less)
How could we achieve this?

Initial high-energy mixing is a critical factor

Polymer swelling time, $t_s \sim (\text{diameter})^2$  

Tanaka (1979)*

Assume $t_s \rightarrow 1 \text{ min}$

$t_s \rightarrow 100 \text{ min}$

Initial high energy mixing (DD4) $\rightarrow$ No fisheye formation $\rightarrow$
Significantly shorter mixing time $\rightarrow$ Minimum damage to polymer structure $\rightarrow$
Better quality polymer solution $\rightarrow$ Polymer savings

Thank You

Please contact Yong Kim with any questions

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Questions & Answers