Fluid Dynamics and Chemistry in Effective Polymer Mixing for Improved Flocculation

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Presentation Overview

- Why Polymer?
- Characteristics of Polymer
- Effect of Dilution Water Chemistry
- Effect of Mixing Energy/Strategy
- Exemplary Polymer Systems
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
# Coagulants and Flocculants

<table>
<thead>
<tr>
<th>Coagulants (low mol. wt.)</th>
<th>Inorganic</th>
<th>Cationic</th>
<th>Alum, Ferric Chloride Polyaluminum Chloride (PAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>Cationic</td>
<td></td>
<td>PolyDADMAC Epi./DMA</td>
</tr>
<tr>
<td>Flocculants (high mol. wt.)</td>
<td>Organic</td>
<td>Cationic</td>
<td>Acrylamide/amine copolymer Mannich polymer</td>
</tr>
<tr>
<td></td>
<td>Anionic</td>
<td></td>
<td>Acrylamide/acrylate copolymer</td>
</tr>
<tr>
<td></td>
<td>Nonionic</td>
<td></td>
<td>Polyacrylamide Polyethylene oxide</td>
</tr>
</tbody>
</table>
Structure of Polymer

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

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

\[
\begin{align*}
\text{CO} & \quad \text{CO} & \quad \text{CO} \\
\text{NH}_2 & \quad \text{NH}_2 & \quad \text{NH}_2
\end{align*}
\]

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”

\[
\begin{align*}
n &= \frac{10,000,000}{71} \\
   &= 140,850
\end{align*}
\]

(mol. wt. of monomer, acrylamide = 71)
High Molecular Weight Polymers

**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

**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 2 µm
- Cost: very high
Emulsion Polymer - 40% active

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

To maximize the value of Inverting Surfactant*
* Higher polymer concentration first (1%)
* Post-dilution to feed concentration (0.5%, 0.25%)

*d = 0.1 to 2 µm

* 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

1.0%

Water 100 gph

Secondary Mixing

Water 100 gph

0.5% solution

Polymer 1 gph

0.5%

Water 200 gph

0.5% solution
Storage of Emulsion Polymer

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

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

Separated Oil → Settled Out Polymer Gels

Separation (stratification) involves using equipment like drum (tote) mixers and recirculation pumps to separate the emulsion polymer into distinct layers. Moisture intrusion is managed by using a drum (tank) dryer to ensure moisture content is kept within specified limits.
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
Effect of Dilution Water Hardness

Soft water helps polymer chains to be fully extended

Effect of Chlorine (Oxidizing Chemical)

Oxidizing chemicals break down polymer chains

![Graph showing the effect of chlorine concentration on viscosity](image)
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

Characteristics of Polymer Activation

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

**Dissolution stage:**
- negligible agglomerability
- low-energy mixing
- minimize polymer fracture
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 → significant increase in polymer solution viscosity

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

- The Original PolyBlend® System
- Proven performance
- Two-Stage mixing
- Rugged
- Economical
- Portable
- Space saving
- Optional A-control
- Ship next day
PolyBlend® M Series

- Open-Frame Design
- Easy Installation & Maintenance
- Direct Drive Mixing
- Variable Speed Mixing

- Choice of Polymer Pumps
- On-board Post-dilution
- Optional Custom Controls*
  - A, B, C Control

Monterey Regional WWTP, CA
PolyBlend Dry Polymer System

High Energy Mixing
G = 15,000 /sec
(3,450 rpm, <0.5 sec)

Low Energy Mixing
(58 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

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

Disperses Individual Polymer Particles

* No Fisheye Formation
* Shorter Mixing Time in Next Stage
Why initial high-energy mixing is critical?

Polymer swelling time, \( t_s = k (\text{diameter})^2 \)  

\textit{Tanaka (1979)*}

![Diagram showing swelling time](https://via.placeholder.com/150)

Assume \( t_s \rightarrow 1 \text{ min} \)

Initial high-energy mixing (DD4) → No fisheye formation → Significantly shorter mixing time → Minimum damage to polymer structure → Better quality polymer solution → Less polymer consumption

Mixing Tank for Dissolution of Dry Polymer

Patented Hollow-Wing Impeller
  - No Weissenberg Effect

Large Impeller, 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
Weissenberg Effect

* Polymer solution exceeding “critical concentration” climbs up mixing shaft
* Extremely non-uniform mixing
* Critical factor in designing polymer mix tank - 0.25% limit for HMW polymer
Thank You

Please contact Yong Kim with any questions

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