Fluid Dynamics and Chemistry in Effective Polymer Mixing for Improved Flocculation

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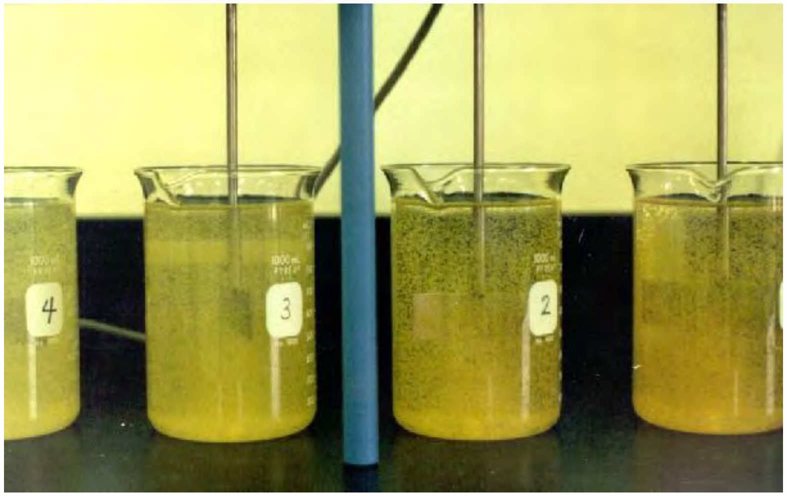
Presentation Overview

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

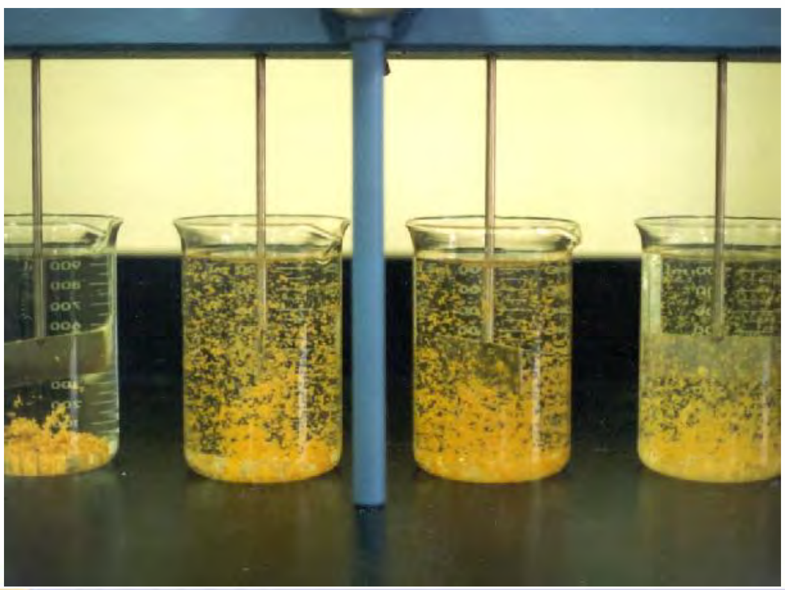
Coagulation and Flocculation



Coagulation

- Double-layer compression (charge neutralization)
- Enmeshment (sweep coagulation)

- Clay suspension + Ferric chloride

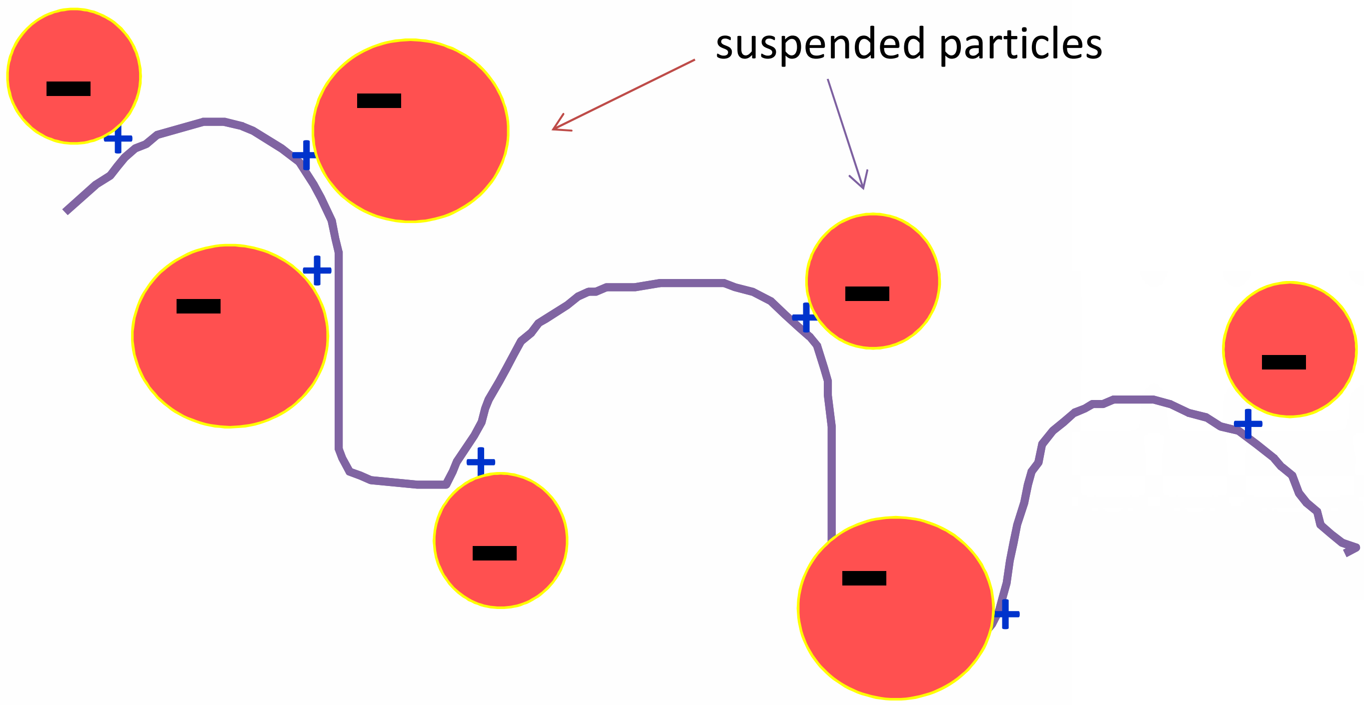


Flocculation

- 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

Coagulants (low mol. wt.)	Inorganic	Cationic	Alum, Ferric Chloride Polyaluminum Chloride (PAC)
	Organic	Cationic	PolyDADMAC Epi./DMA
Flocculants (high mol. wt.)	Organic	Cationic	Acrylamide/amine copolymer Mannich polymer
		Anionic	Acrylamide/acrylate copolymer
		Nonionic	Polyacrylamide Polyethylene oxide

Structure of Polymer

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

$$\ldots - CH_2 - \underset{\underset{NH_2}{|}}{\underset{CO}{CH}} - [CH_2 - \underset{\underset{NH_2}{|}}{\underset{CO}{CH}}]_n - CH_2 - \underset{\underset{NH_2}{|}}{\underset{CO}{CH}} - \ldots$$

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"*

$$n = 10{,}000{,}000 / 71$$
$$= 140{,}850$$

(mol. wt. of monomer, acrylamide = 71)

High Molecular Weight Polymers

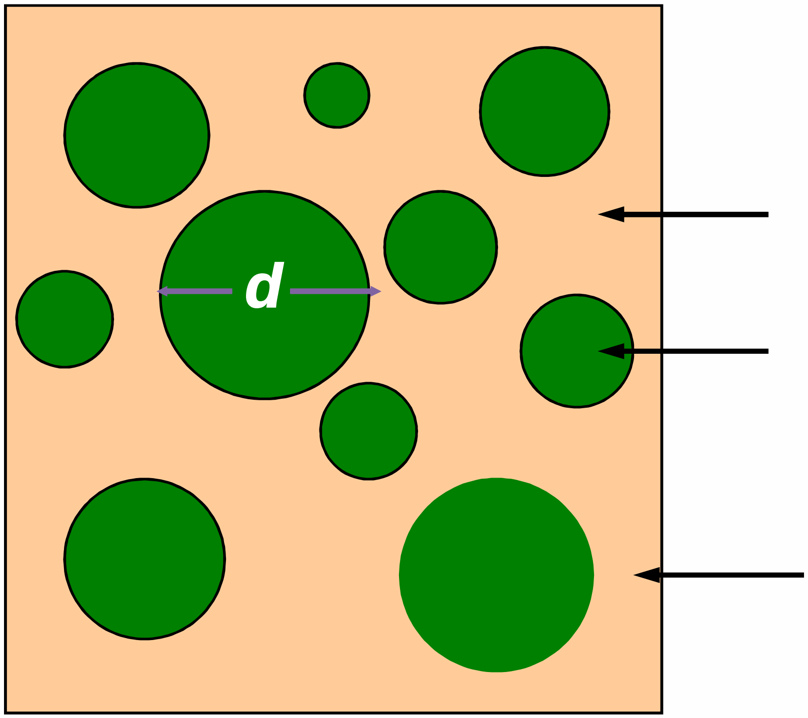
Dry Polymer

- 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

d = 0.1 to 2 µm

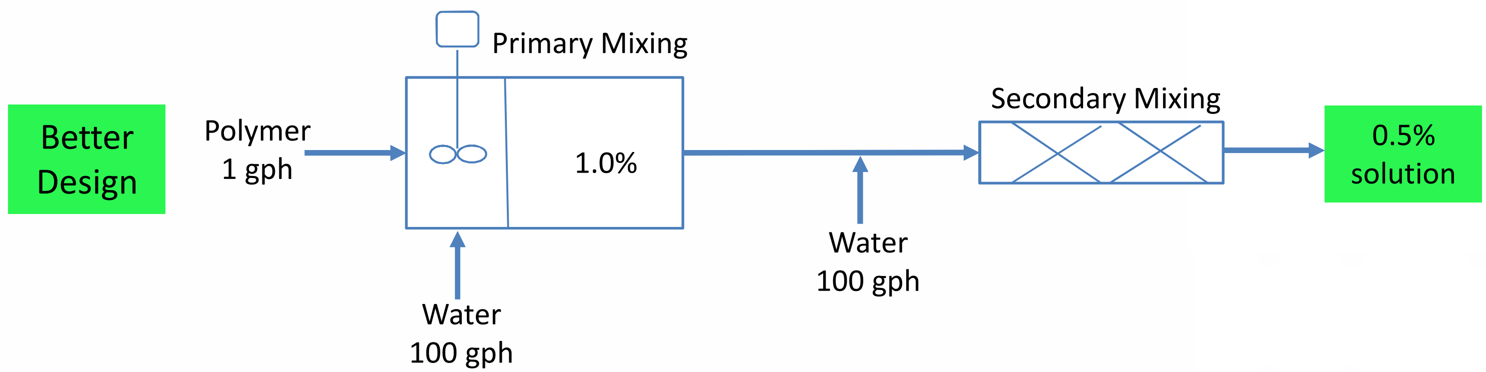
To maximize the value of Inverting Surfactant*

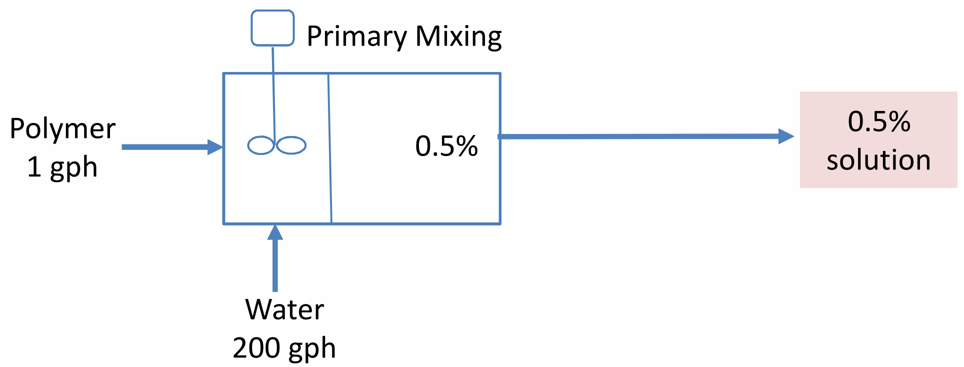
* Higher polymer concentration first (1%)
* Post-dilution to feed concentration (0.5%, 0.25%)

* 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 %





Storage of Emulsion Polymer

- Separation (stratification)

  * Drum (Tote) Mixer

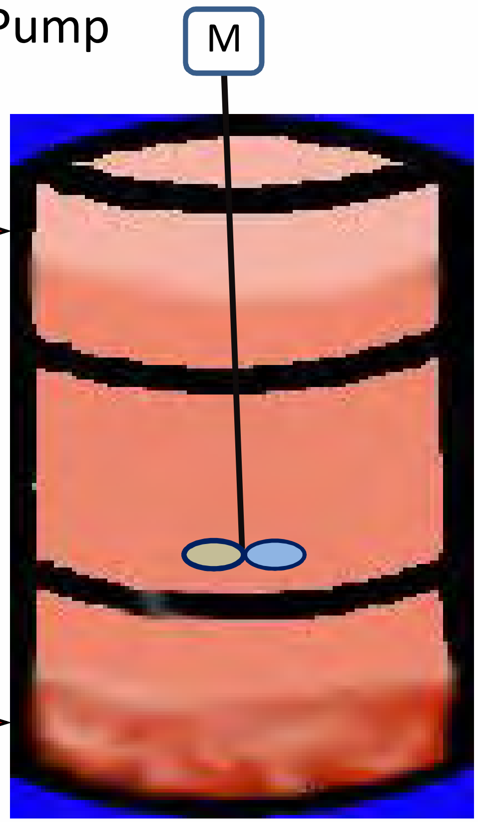
  * Recirculation Pump

- Moisture Intrusion

  * Drum (Tank) Dryer

Separated Oil

Settled Out Polymer Gels



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

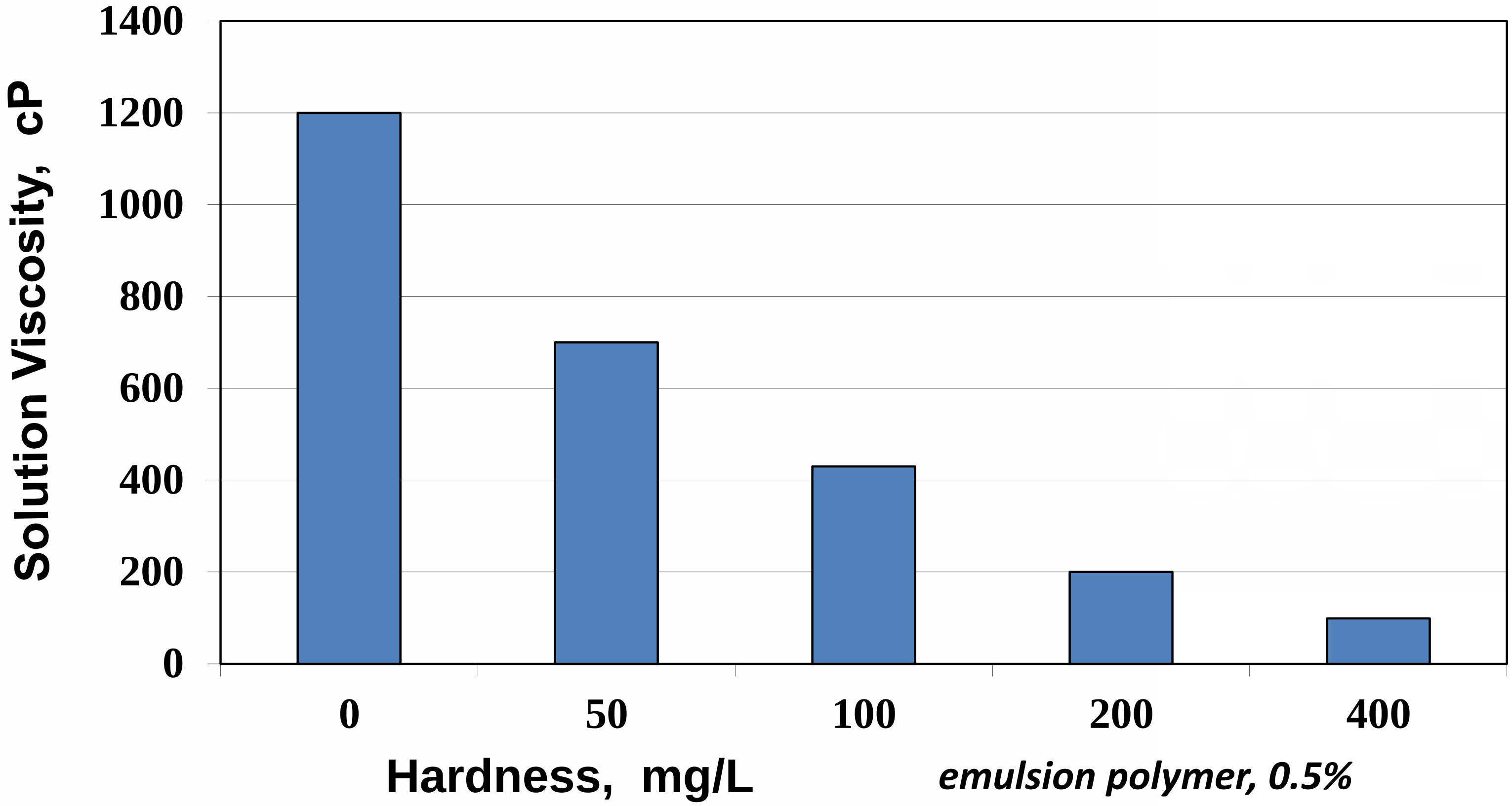
- In-line water heater for water lower than 40 ºF
- Water over 100 ºF may damage polymer chains

Suspended solids: strainer recommended if > 10 ppm

pH: negligible effect within pH 3 - 10

Effect of Dilution Water Hardness

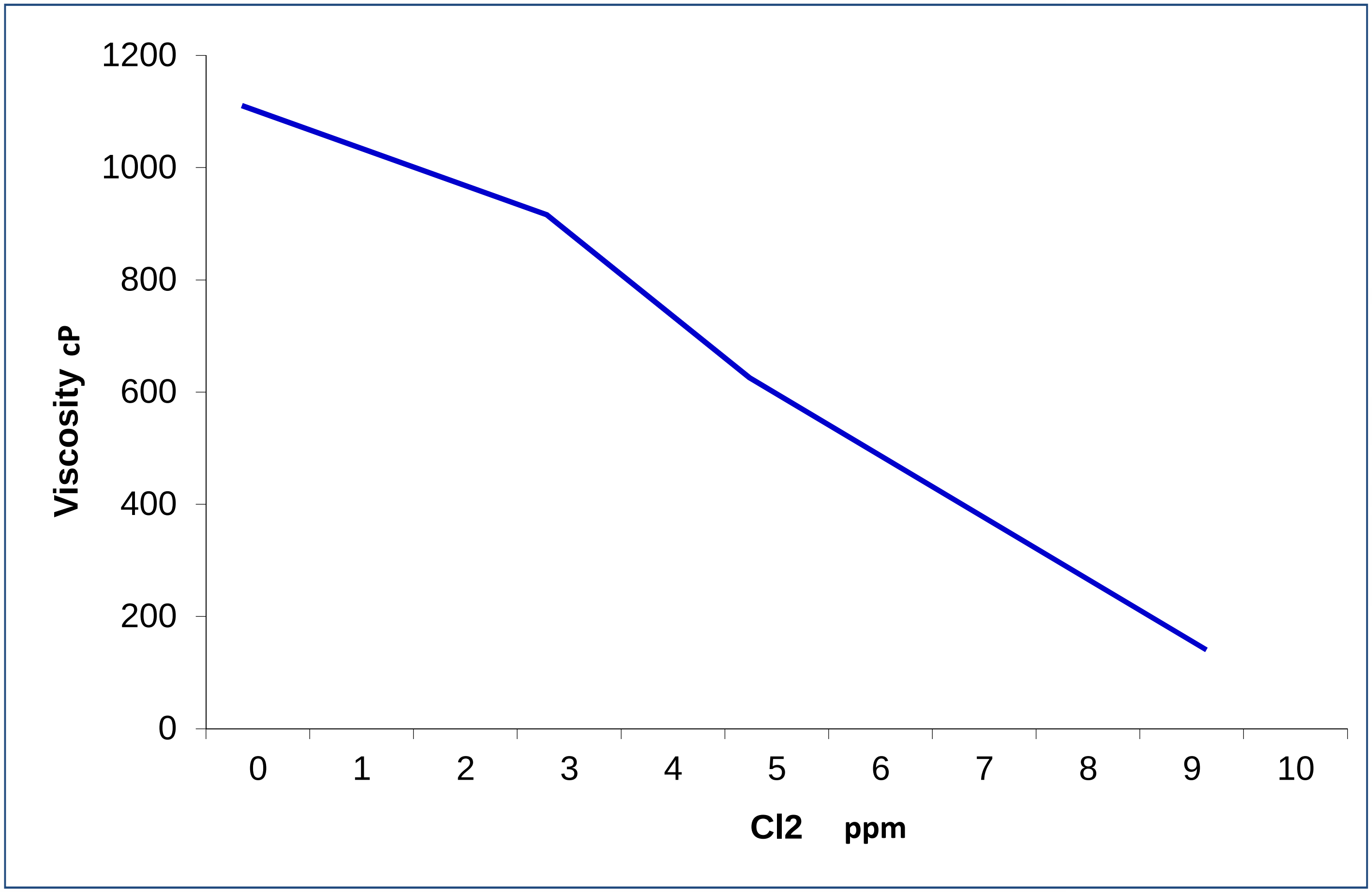
Soft water helps polymer chains to be fully extended



Kim, Y.H., Coagulants and Flocculants: Theory and Practice, 43, Tall Oak Pub. Co. (1995)

Effect of Chlorine (Oxidizing Chemical)

Oxidizing chemicals break down polymer chains



Polymer Activation (Dissolution)

1. Initial Wetting (Inversion)

Sticky layer formed

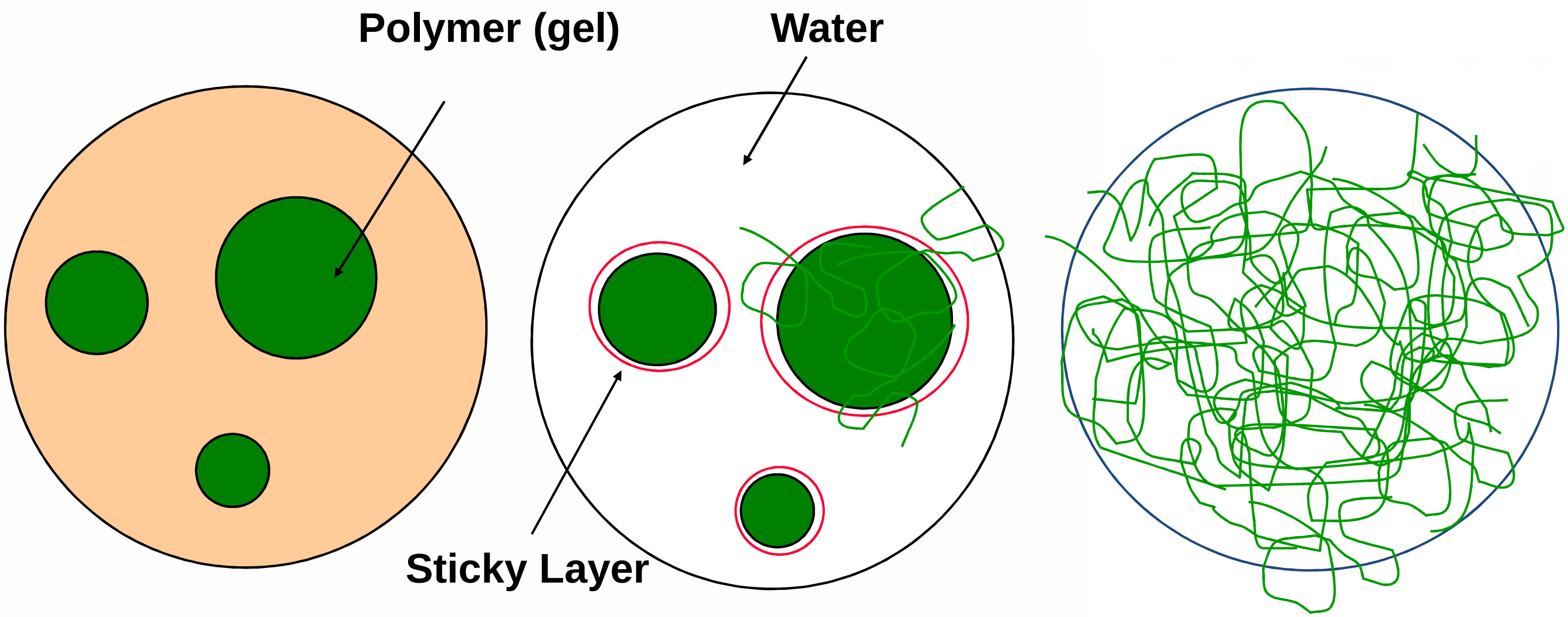
High-energy Mixing Required

2. Dissolution

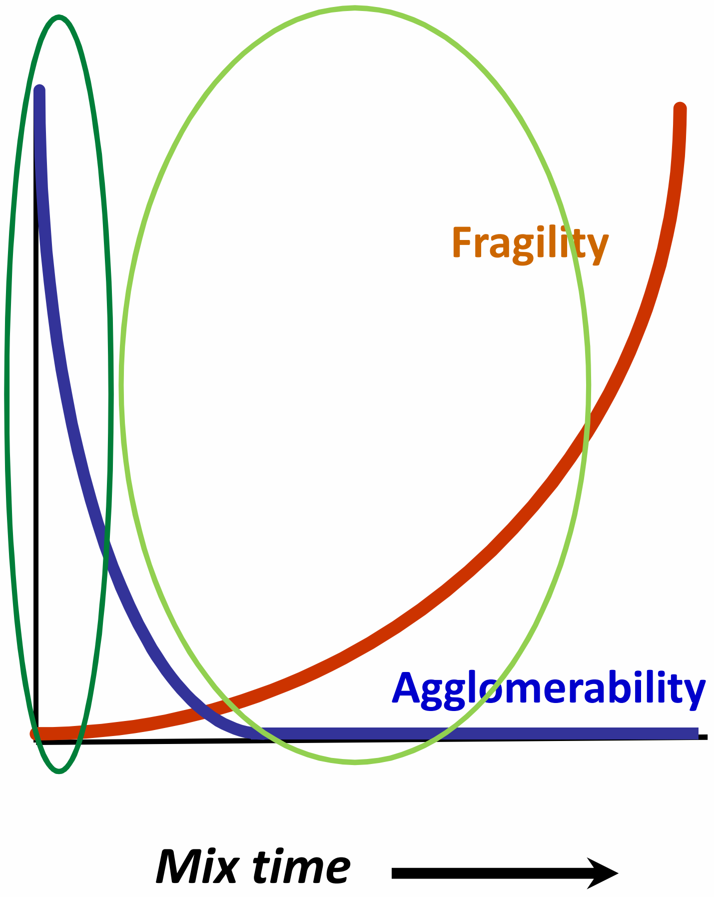
"Reptation" by *de Gennes (1971)**

Low-energy Mixing Required

* de Gennes, P.G., *J. Chem. Phys.*, 55, 572 (1971)



Characteristics of Polymer Activation



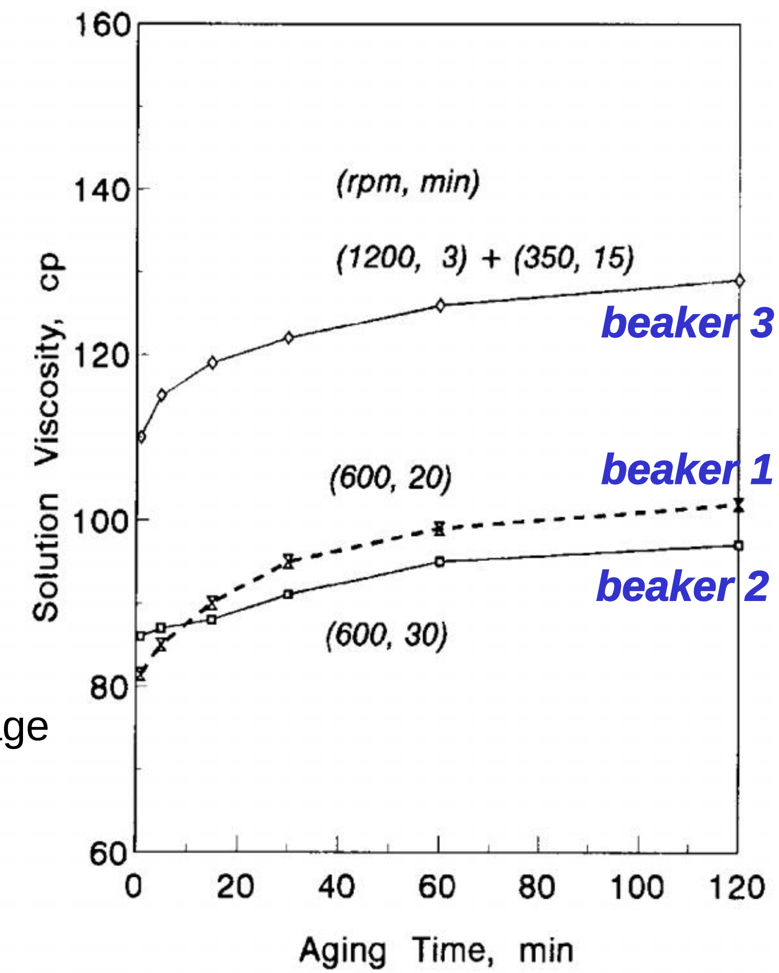
Initial wetting stage:
- negligible fragility
- very high-energy mixing
- minimize fisheye formation

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



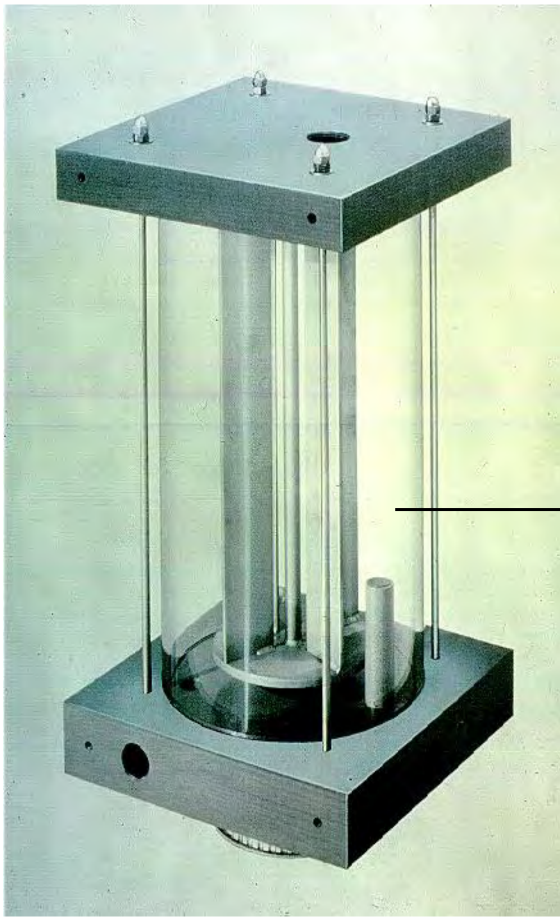
Two-stage mixing resulted in polymer solution of much better quality

* High energy first: prevent fisheye formation

* Low energy followed: minimize polymer damage

Development of Two-stage Mixer

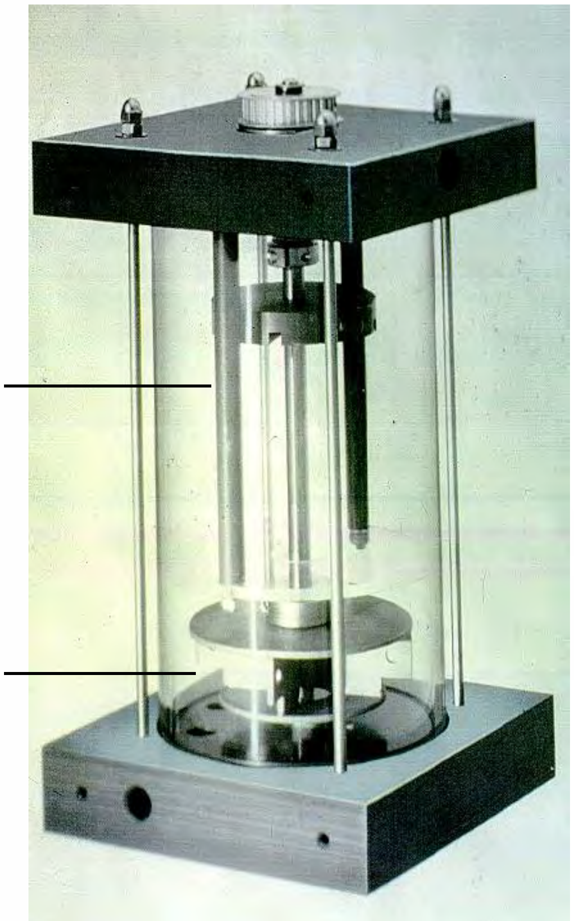
1- stage mixer



1,700

2- stage mixer

1,100



4,000

G-value, mean shear rate (sec^{-1})

Mixing Effect on Polymer Activation

Two-stage mixing → significant increase in polymer solution viscosity

Polymer	Mixing unit	Conc. %	Viscosity cP
Anionic	1-stage 2-stage	0.50	226 310 **(27%↑)**
Cationic	1-stage 2-stage	0.50	427 523 **(18%↑)**
Nonionic	1-stage 2-stage	0.50	156 178 **(12%↑)**

PolyBlend® PB Series

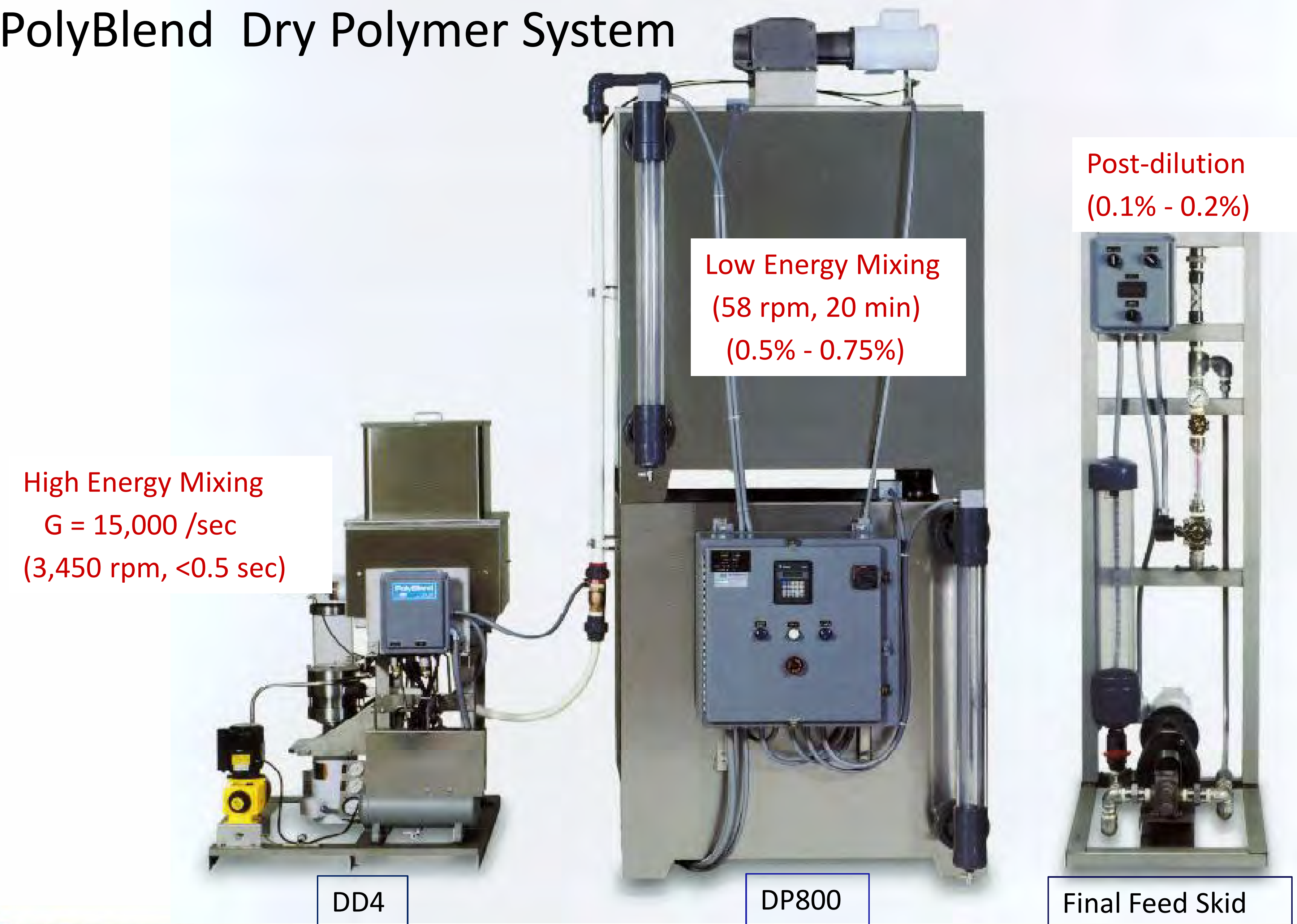
- The Original PolyBlend® System
- Proven performance
- Two-Stage mixing
- Rugged
- Economical
- Portable
- Space saving
- Optional A-control
- Ship next day

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



Dry Disperser (DD4) for Initial Wetting

Very High-Intensity Mixing for Short Time

G = 15,000 /sec

@ 3,450 rpm

for < 0.5 sec

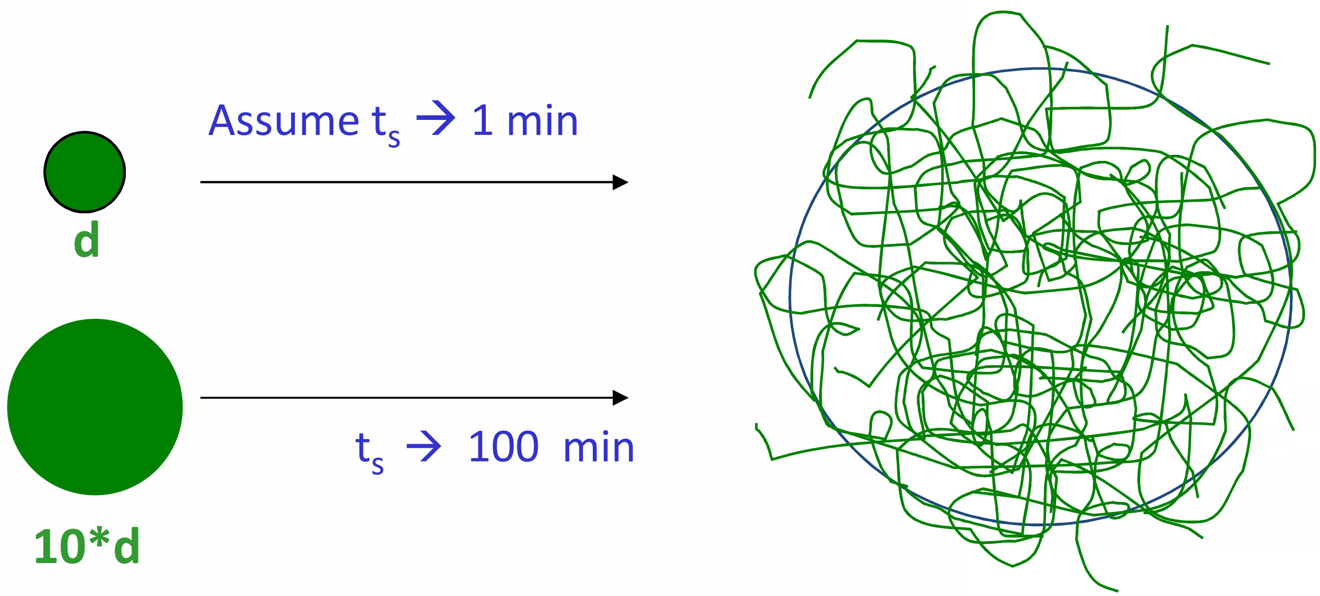
Disperses Individual Polymer Particles

* No Fisheye Formation

* Shorter Mixing Time in Next Stage

Why initial high-energy mixing is critical?

Polymer swelling time, $t_s = k\,(\text{diameter})^2$ *Tanaka (1979)**



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

* Tanaka, T., Fillmore, D.J., *J. Chem. Phys*., 70 (3), 1214 (1979)

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

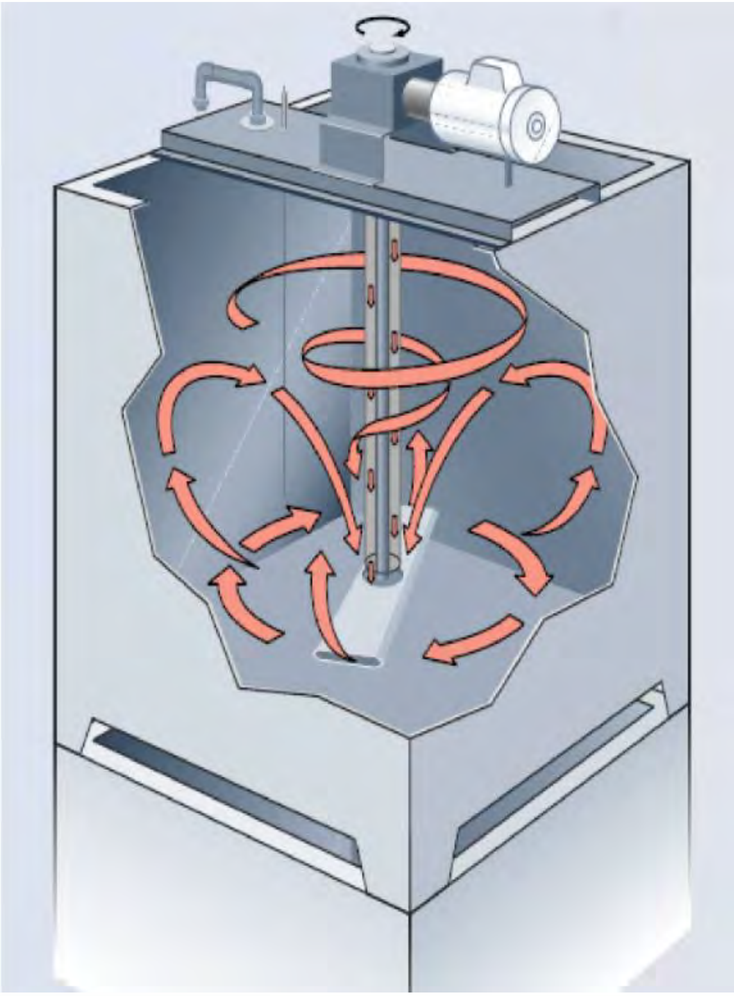
- Low-intensity Mixing
- Minimize Damage to Polymer Chain

Square Tank Design

- No Wessenberg Effect
- No Baffles Needed, No Dead Zone

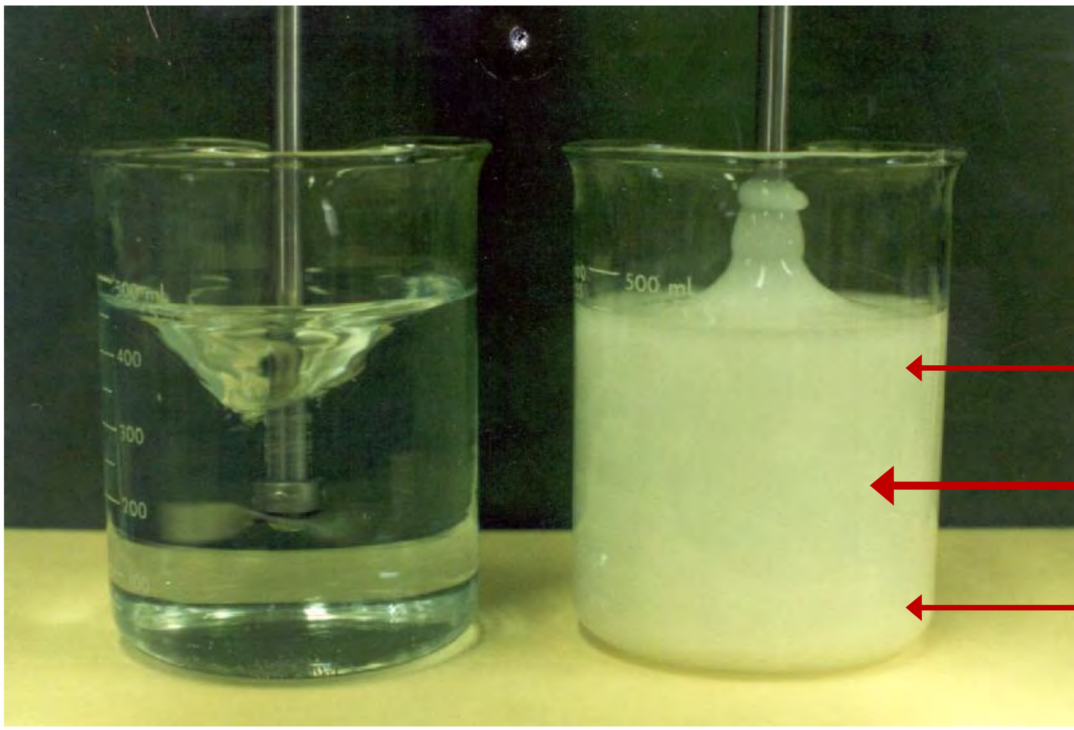
Shorter Mixing Time – Due to DD4

- 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



extremely low mixing

very high mixing

extremely low mixing

Water
(Newtonian)

Polymer Solution
(Non-Newtonian, Pseudoplastic)

Thank You

Please contact Yong Kim with any questions

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