

How to Optimize Polymer Efficiency for Better Sludge Dewatering

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Presentation Overview

1. Basics of Polymer

- Chemistry, handling, application
- Viscosity as an indicator of polymer solution quality
- Effect of dilution water

2. Science of Polymer Activation

- Two-stage mixing: dry and emulsion polymers
- Two-step dilution: emulsion polymers
- Residence time: polymer uncoiling/dissolution

3. Case Studies

- Neshaminy Water Treatment Plant, PA – emulsion polymer
- Fairfield-Suisun Sewer District – dry polymer

Coagulants and Flocculants

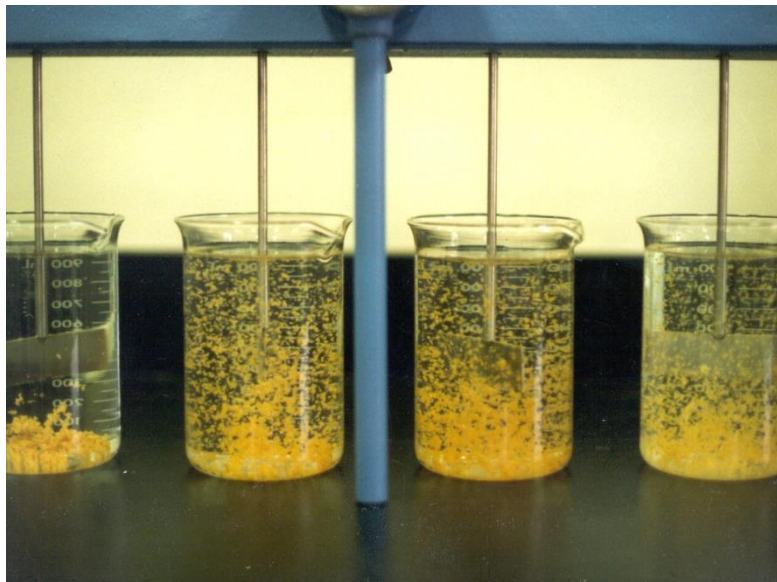
<i>Coagulant (low mol. wt.)</i>	<i>Inorganic</i>	<i>Cationic</i>	<i>Alum, Ferric Chloride Polyaluminum Chloride (PAC)</i>
	<i>Organic</i>	<i>Cationic</i>	<i>PolyDADMAC Epi/DMA</i>
Flocculant (high mol. wt.)	Organic	Cationic	Acrylamide/amine copolymer Mannich polymer
		Anionic	Acrylamide/acrylate copolymer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

Coagulation and Flocculation



Coagulation

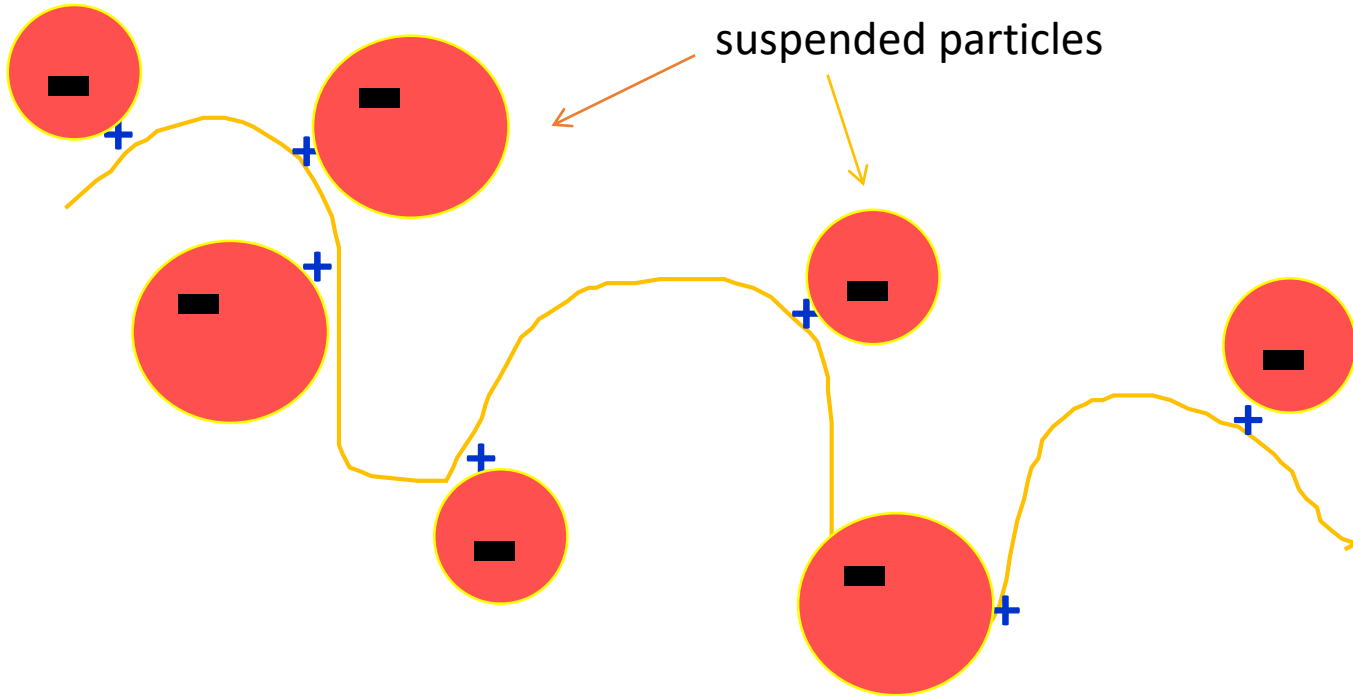
- Double-layer compression (charge neutralization)
- Enmeshment (sweep coagulation)
- Clay suspension + Ferric chloride (40 - 120 mg/L)



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

Three Forms of Polymer Solutions



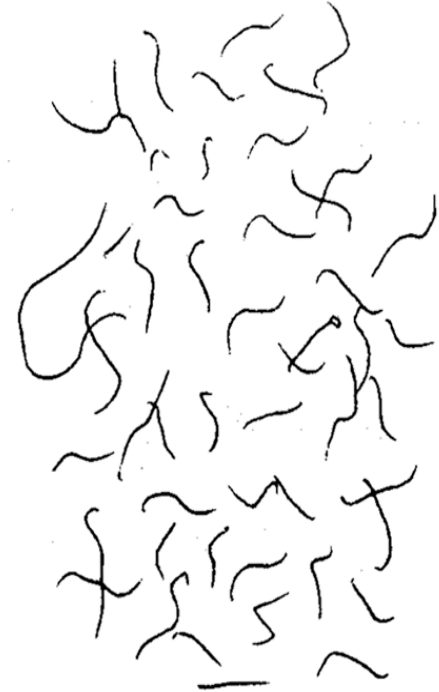
Neat polymer



Fisheyes due to poor
initial wetting



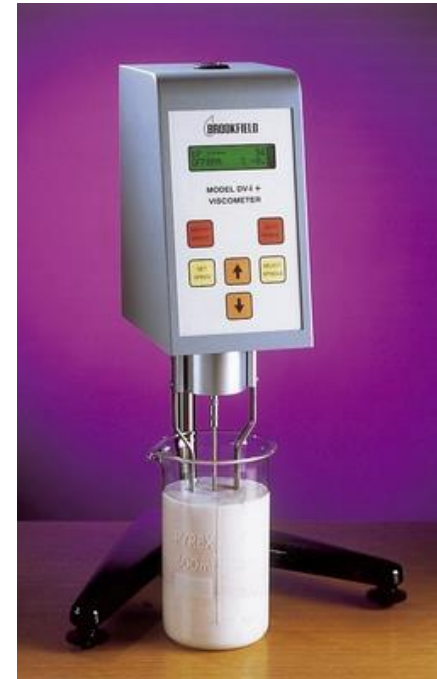
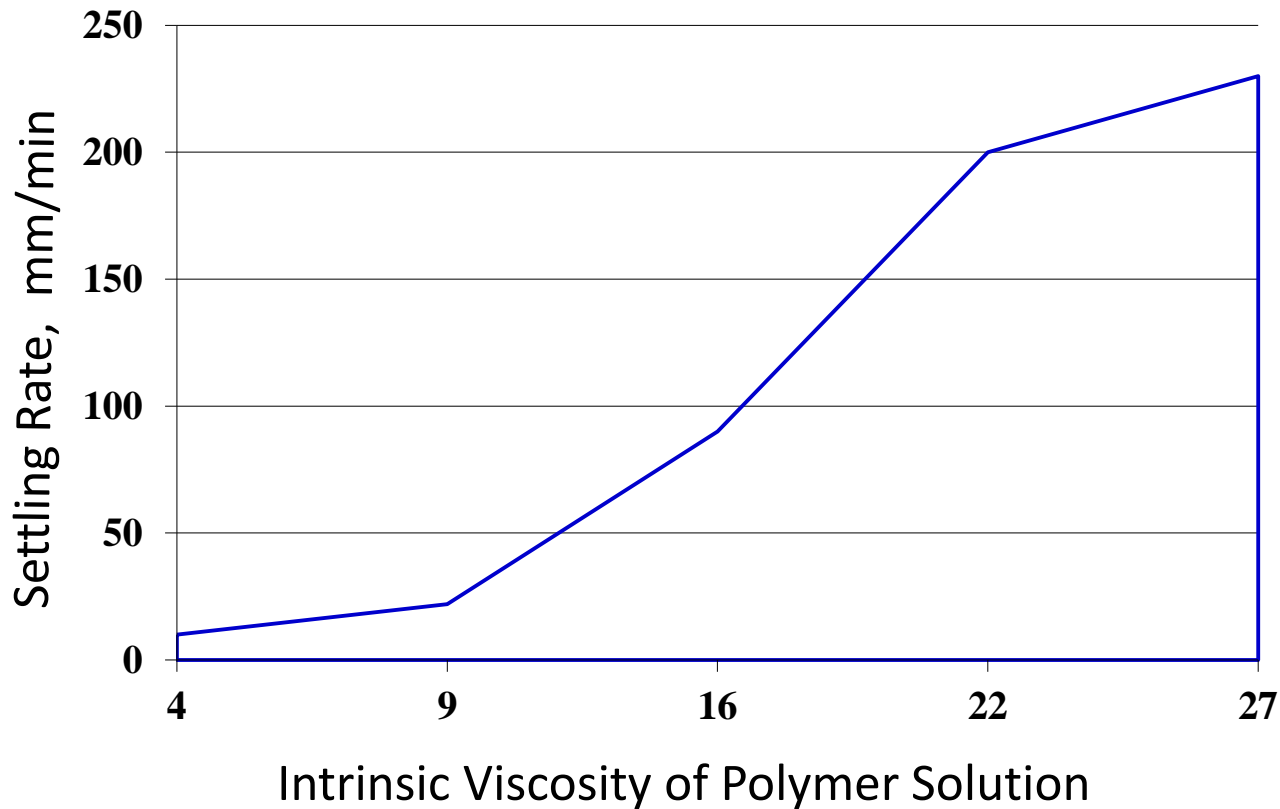
Ideal polymer chains by
two-stage mixing



Broken polymer chains by
conventional batch mixing

Viscosity – Indicator of Polymer Solution Efficiency

- Quantity of friction as measured by the force resisting a flow in which parallel layers have at unit speed relative to one another




Sakaguchi, K.; Nagase, K., Bull. Chem. Soc. Japan, 39, p.88 (1966)

Polymer supplier data sheet provides a starting point for **viscosity** – critical factor for **polymer efficiency**

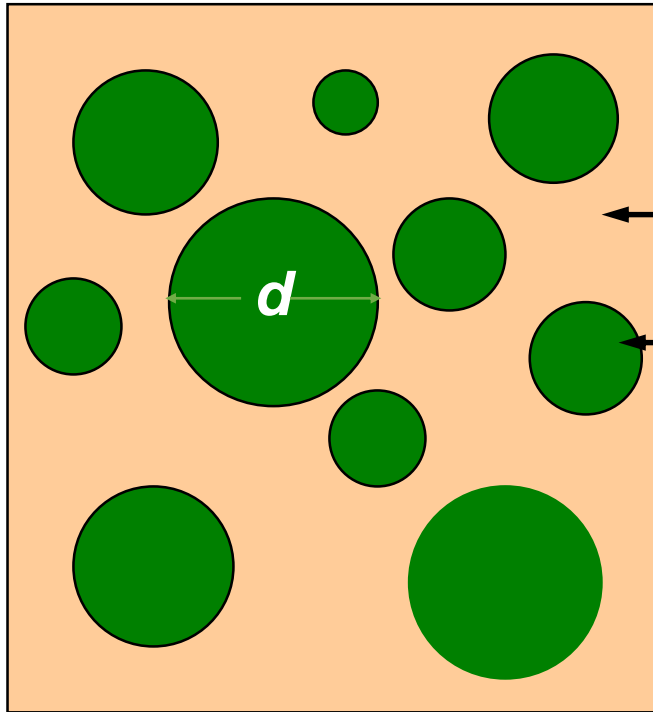
Solenis, Inc.

Table of Properties - PRAESTOL® Cationic Polymers (Emulsion)



PRAESTOL POLYMER GRADE	CATIONIC CHARGE	ACTIVE CONTENT	DENSITY (GR/ML)	PRODUCT VISCOSITY (CP)	SOLUTION VISCOSITY 1% IN DIST. WATER ⁽¹⁾ (CP)	SOLUTION VISOCITY 1.0% in 10% NaCl-Brine ⁽²⁾ (CP)	FREEZING POINT (°C)	EFFECTIVE pH RANGE
K105L	Low	30%	1.04	<4000	>5000	>2000	-15	1-10
K110FL	Low	35%	1.03	<4000	>3000	>1000	-15	1-10
K120L	Low-Medium	40%	1.03	<4000	>7000	>500	-15	1-10
K226FLX	Medium	29%	1.03	<4500	>8000	>400	-15	1-10
K144L	Medium	40%	1.03	<4000	>7000	>500	-15	1-10
K122L	High	43%	1.04	<4000	>9000	>300	-15	1-10
K128L	High	43%	1.04	<4500	>9000	>900	-15	1-10
K132L	High	35%	1.01	<5500	>8000	>300	-15	1-10
K133L	High	44%	1.05	<4000	>8000	>150	-15	1-13

Emulsion Polymer - 40% active



Hydrocarbon Oil: 30%

Polymer Gel: Polymer 40%
Water 30%

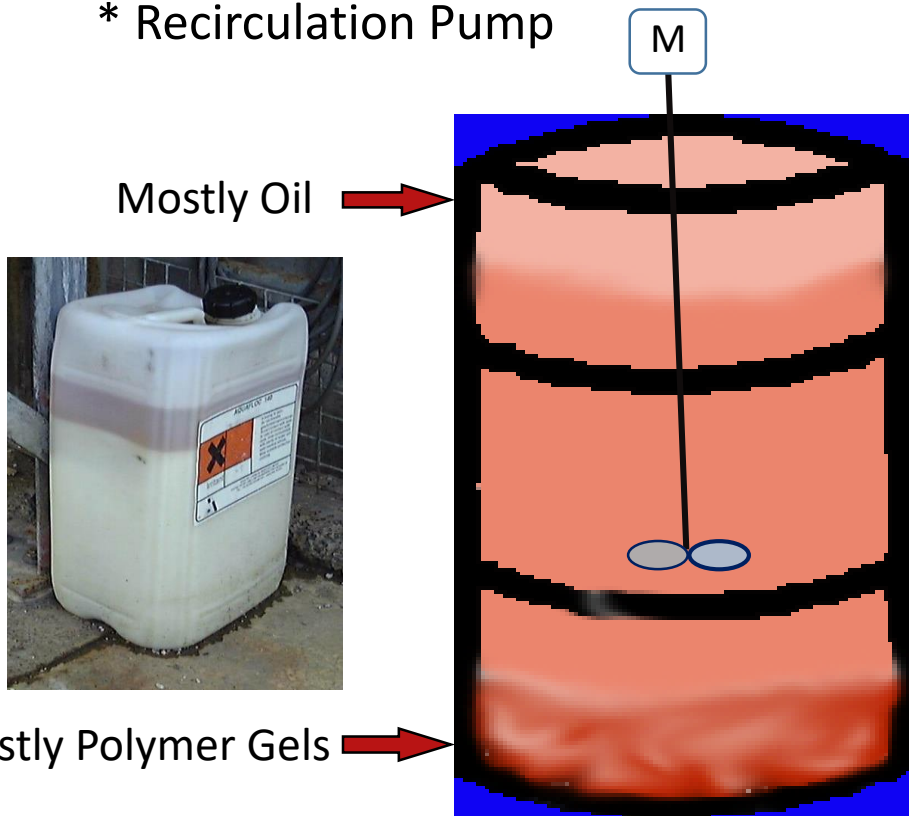
$d = 0.1 \text{ to } 2 \mu\text{m}$

Specific gravity difference between
hydrocarbon oil and polymer gels
→ Separation (Stratification)

Storage of Emulsion Polymer

■ Separation (stratification)

- * Drum (Tote) Mixer
- * Recirculation Pump



■ Moisture Intrusion

- * Drum (Tank) Dryer



Effect of Dilution Water Quality

Ionic strength (Hardness): multi-valent ion hinders polymer activation

- Soft water helps polymer molecules fully-extend faster
- Hardness over 400 ppm may need softener

Oxidizer (chlorine): chlorine attacks/breaks polymer chains

- Should be less than 3 ppm
- Caution in using **reclaimed water** for polymer mixing
 - * Serious negative impact on aging/maturing

Temperature*: higher temperature, better polymer activation

- Water below 40 °F may need water heater
- Water over 100 °F may damage polymer chains

Suspended Solids/ Turbidity:

- In-line strainer recommended
- Caution in using reclaimed water for polymer mixing

**David Oerke, 20% less polymer with warm water, 40% more polymer with 140F sludge, Residuals and Biosolids (2014)*

Polymer Activation (Mixing, Dissolution)

(I) Initial Wetting (Inversion)

Sticky layer formed

High-energy mixing -> No fisheyes

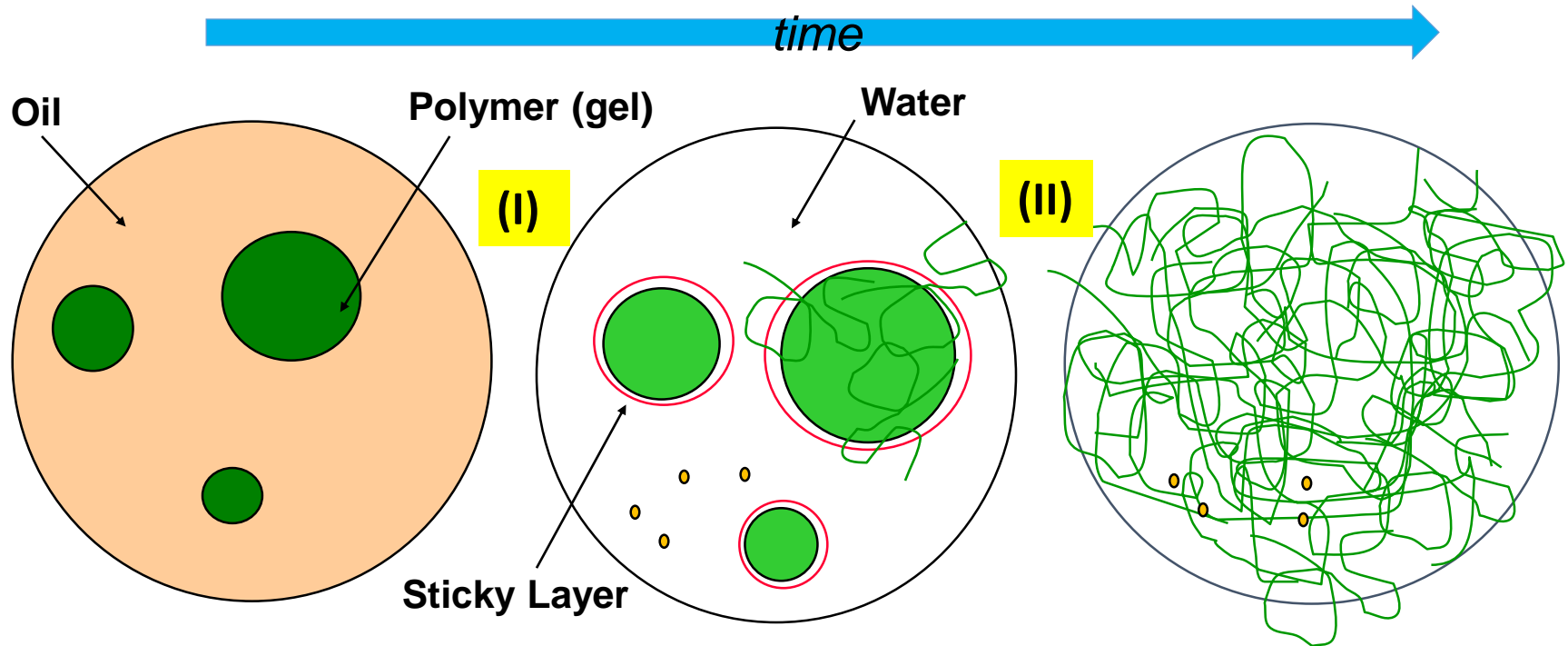
Most Critical Stage (brief)

(II) Dissolution

Reptation* or Uncoiling

Low-energy mixing -> No damage to polymer

Requires longer residence time



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

Two-Stage Mixing (in mix chamber)

higher energy mixing → low energy mixing



CLARIFLOC® WE-1181 POLYMER TYPICAL PROPERTIES

Physical Form	Clear to Milky White Liquid
Cationicity	60%
Active Polyacrylamide Min.	45.0 %
Freezing Point	7 F. (-14 C.)
Flash Point	>200 F. (>93 C.)
Density	TBD

PREPARATION AND FEEDING

CLARIFLOC WE-1181 is a single component emulsion polymer that must be pre-diluted in water before use. In most cases, this product should not be applied neat. One method for dilution is adding the neat polymer into the vortex of a mixed tank at a concentration between 0.25-1.0% polymer (0.5% is optimum) by weight. The polymer can also be injected through a number of commercially available systems that provide in-line mechanical mixing. The best feed systems use initial high energy mixing (>1000 rpm) for a short time (<30 sec) to achieve good dispersion followed by low energy mixing (<400 rpm) for a longer time (10-30 min). Polymer solutions should be aged for 15-60 minutes for best results. Solution shelf life is 8-16 hours.



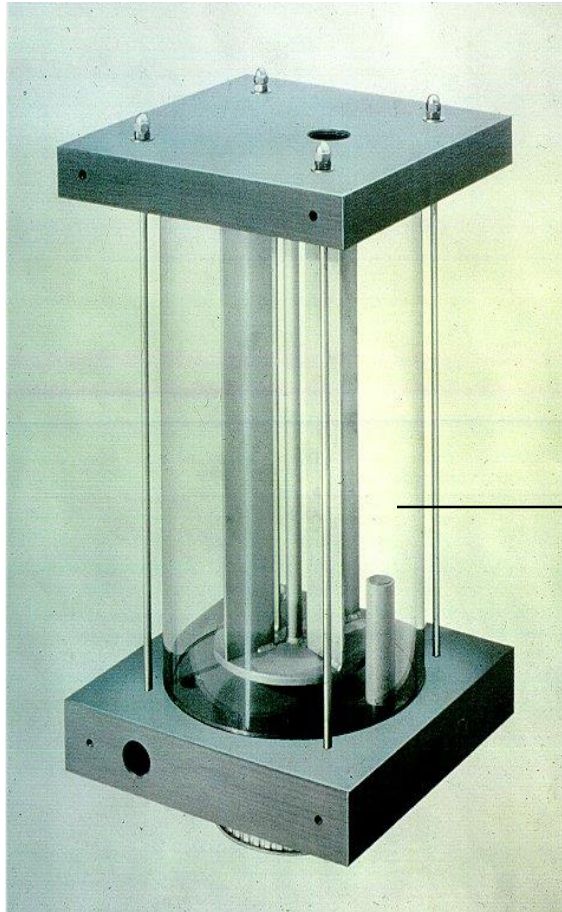
YM-PDS-NA-Praestol Cationic Polymers

There are a number of commercially available automatic feed systems that provide in-line mechanical mixing. The best units of this type feature initial high energy mixing (>1000 rpm) for a short time (<15 sec) to achieve good dispersion of the product into water. This is followed by lower energy mixing (<400 rpm) for a longer period of time (10-20 min) and aging for an additional 10-20 minutes to achieve complete polymer dissolution. Best practice is to use these in-line dilution systems followed by a mixing/aging tank fitted with high/low level probes to refill the tank. The optimum concentration in the mixing/aging tank is 0.5 percent, and in no case should the initial concentration of polymer be less than 0.25 percent for best results.

**“Discrete” Two-Stage Mixing -
discrete means “separation of high
and low energy mixing zones”**

One-Stage vs. Two-Stage Mixer (Emulsion Polymer)

1- stage mixer



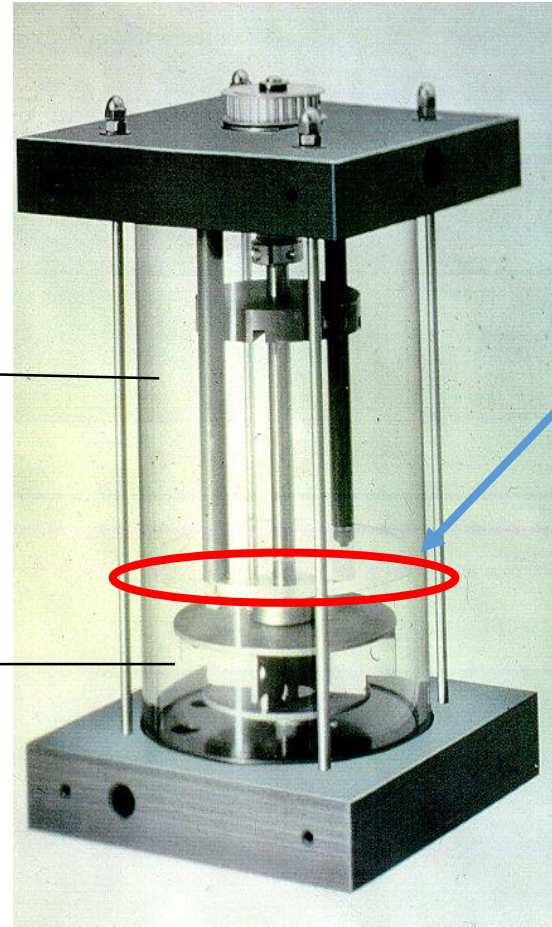
1,700

2- stage mixer

1,100

4,000

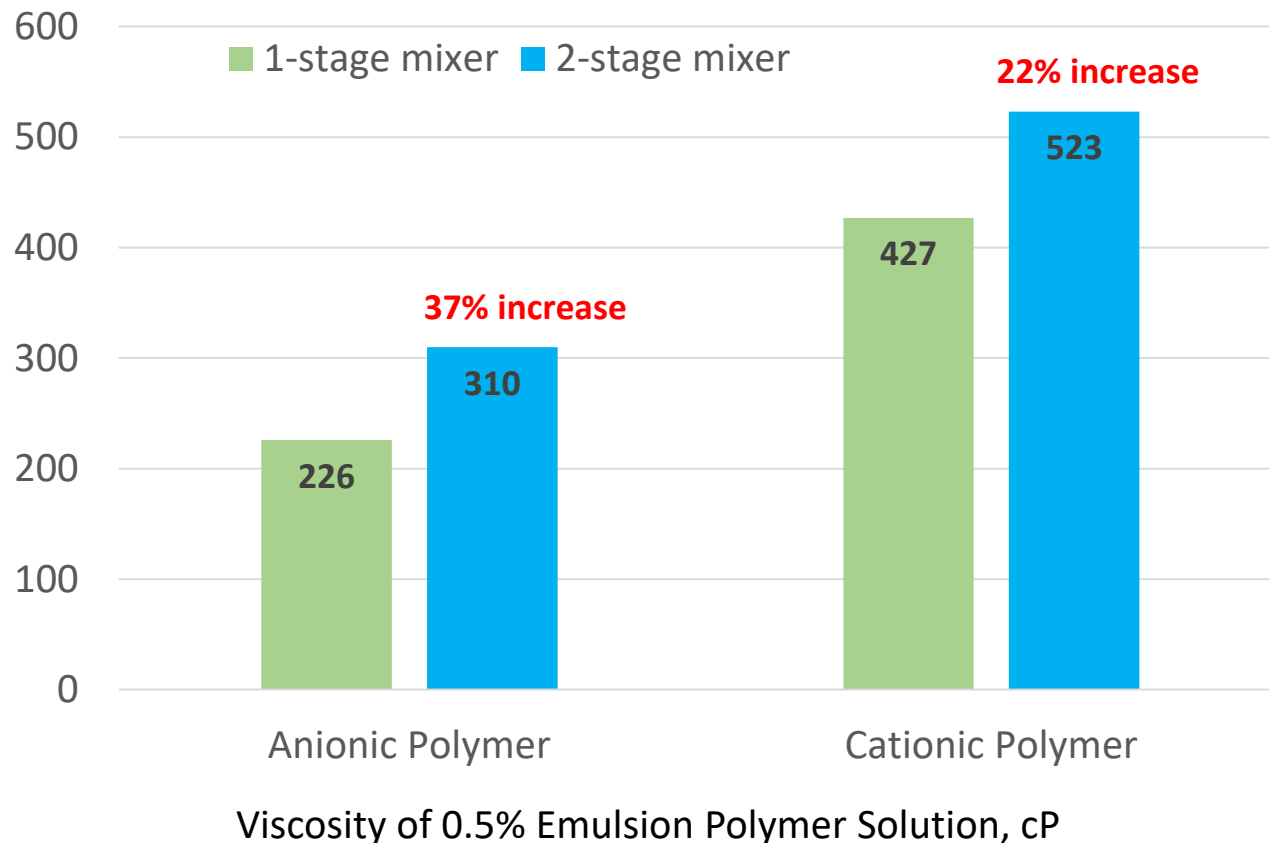
Dividing
Baffle



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

One-Stage Mixing vs. Two-Stage Mixing

Two-stage mixing → significant increase of polymer solution efficiency



Two-Step Dilution - primary mixing (mix chamber) at high conc. (%), then post-dilution for feeding



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PYM-PDS-NA-Praestol Cationic Polymers

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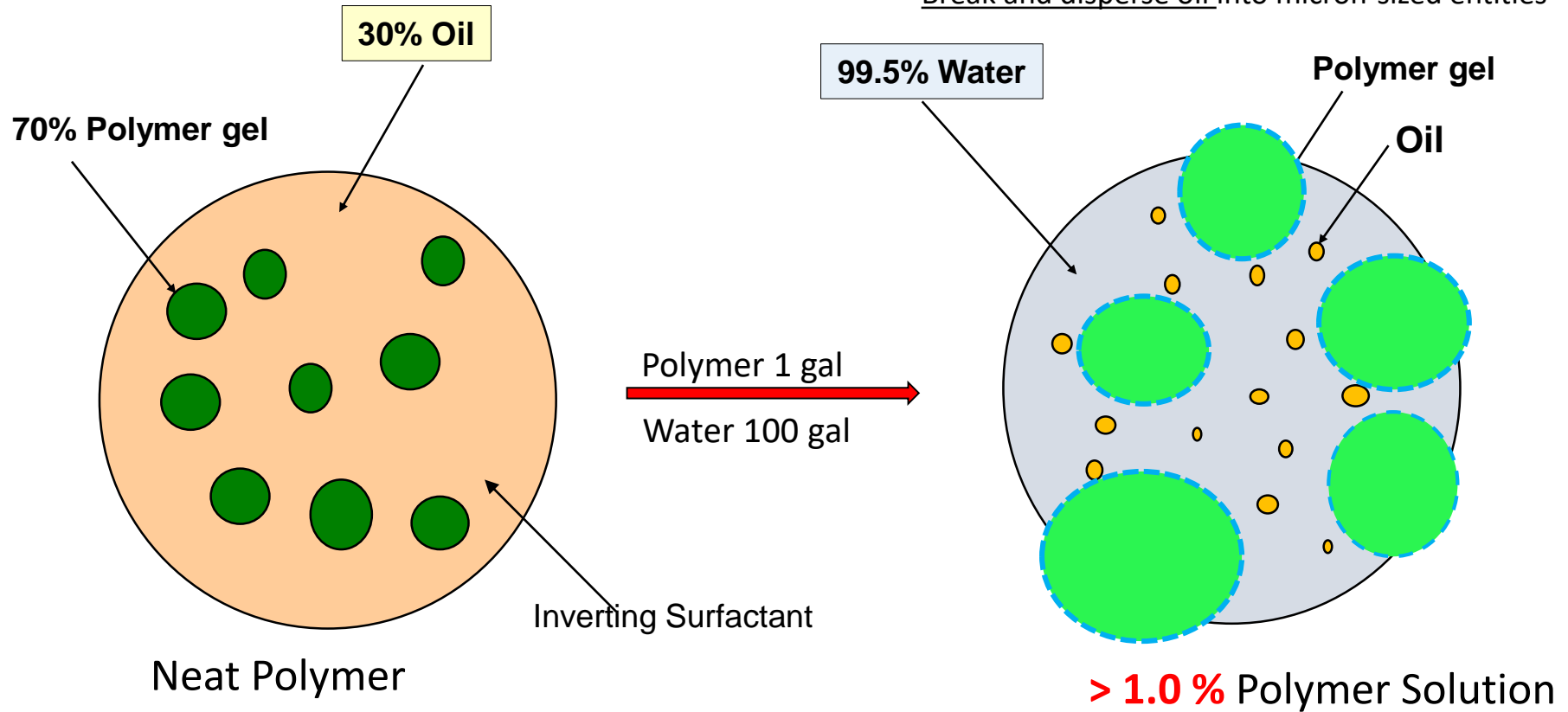
**High Concentration at Initial Wetting,
Optimum 0.5% wt. = 1.0 - 1.5% vol.**

Inversion of Emulsion: water-in-oil → oil-in-water

Especially Important for Clarifier at WTP

Inverting Surfactant

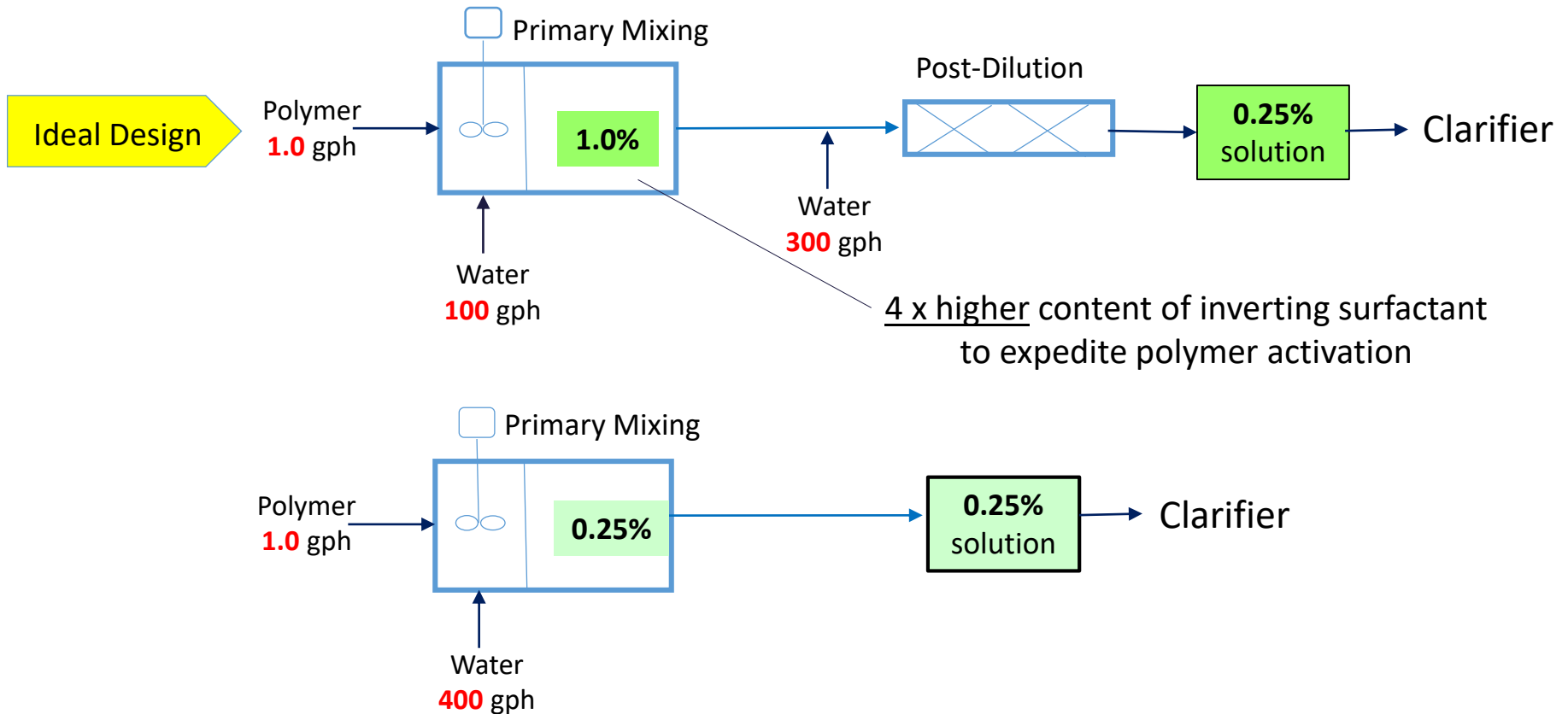
- Strip "oil" off the polymer surface
- Help polymer get exposed to water quickly
- Break and disperse oil into micron-sized entities



* AWWA Standard for Polyacrylamide (ANSI-AWWA B453-06), 11, 2006

Two-Step Dilution: Expediting Polymer Activation

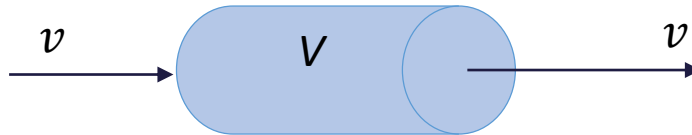
Primary mixing at “high %” → Post-dilution to feed %



Residence Time (in mix chamber)

Sufficient residence time of low-energy mixing zone is required for complete polymer dissolution

$$t = \frac{V}{v}$$



Residence time (t) in flocculating basin: Gt -value

Gt -value = mean shear rate \times residence time

Contact time (T) in clear well design: CT calc

CT calc = residual chlorine concentration \times contact time

Residence time (t) in polymer activation

Second stage of polymer activation – “uncoiling” of long chain polymer molecules requires more time under low energy mixing than high energy first stage mixing

Residence Time of Low Energy Mixing Zone



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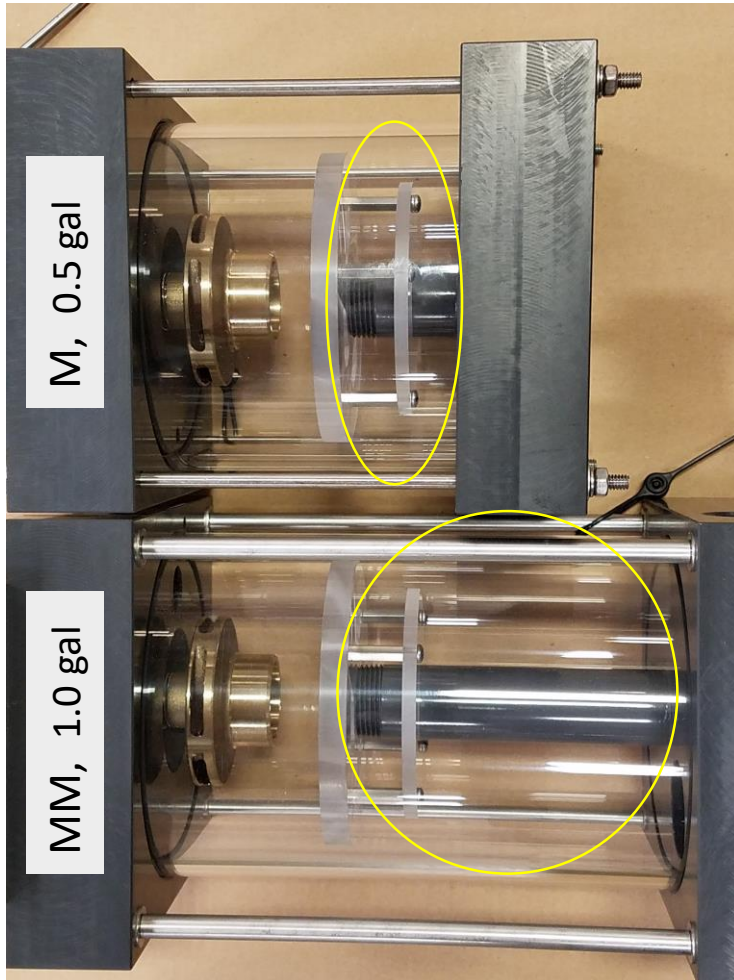


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Low energy mixing stage requires
"longer" residence time than initial
high energy mixing stage

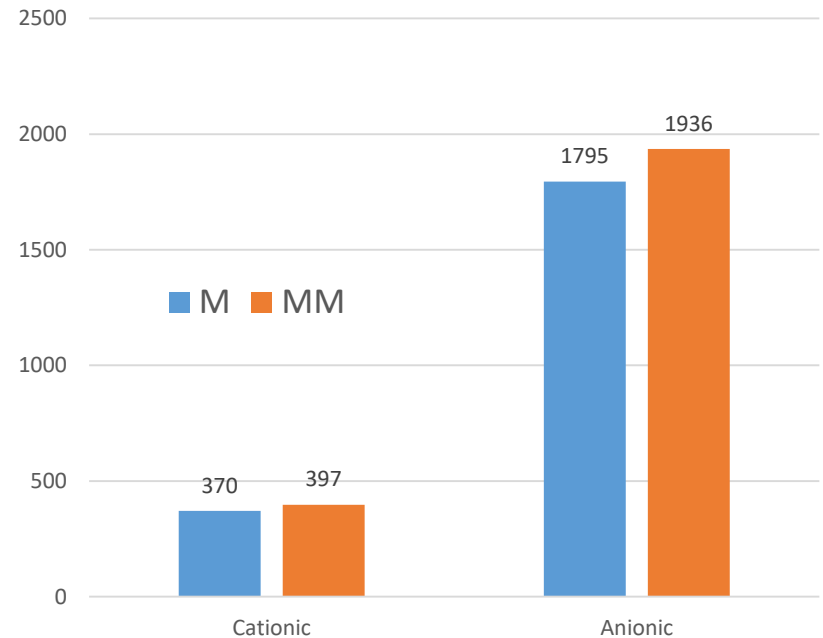
Effect of Residence Time in Mix Chamber



Volume of low-energy zone: V_L

$$V_{L,MM} = 3 * V_{L,M}$$

Effect of Residence Time in Mix Chamber
(0.5% polymer solution viscosity, cP)



Case Study: Emulsion Polymer System

Neshaminy Water Treatment Plant, PA

- Located Northeast Philadelphia
- Operating capacity: 16 MGD
- Population served: 40,000
- Emulsion polymer use for dewatering alum-carbon sludge with two 2-M belt filter presses (K-S)



Performance Comparison of Two Mix Chambers



Existing Polymer System

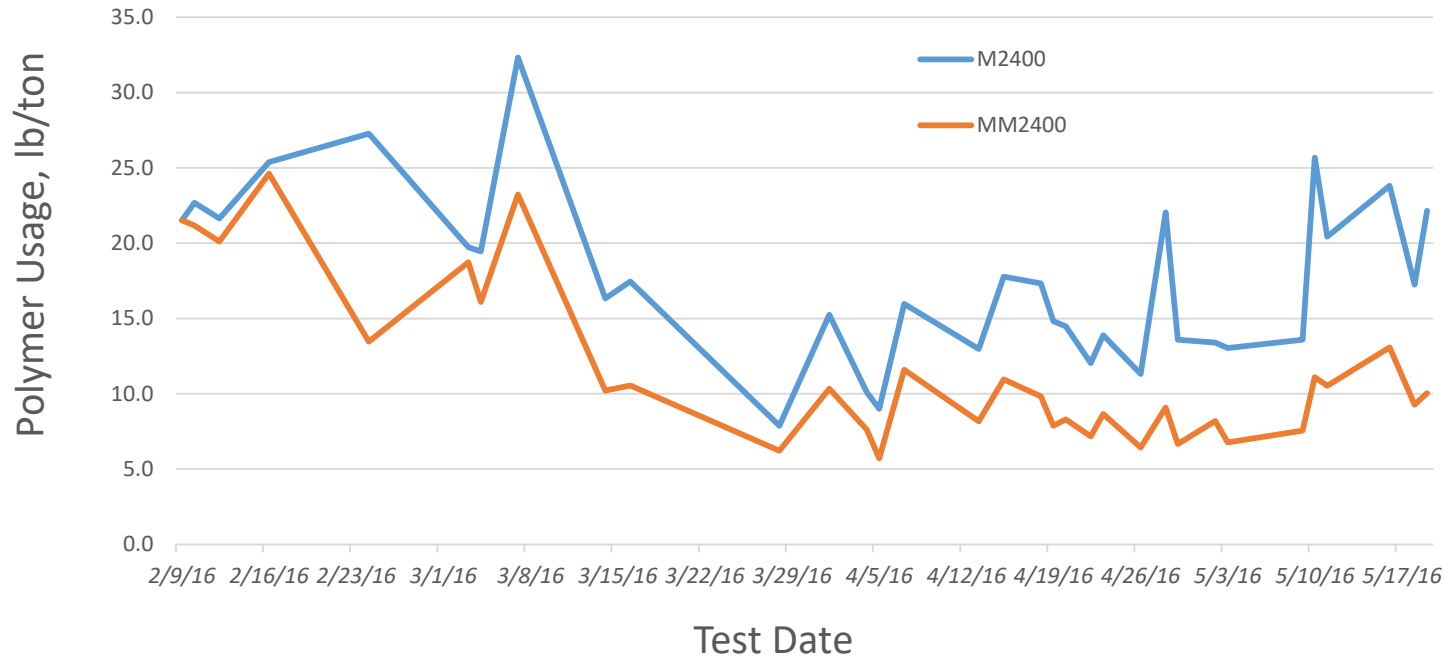
Siemens M1200-D10AA (2011)

New Polymer System

UGSI MM1200-D10AA (2016)

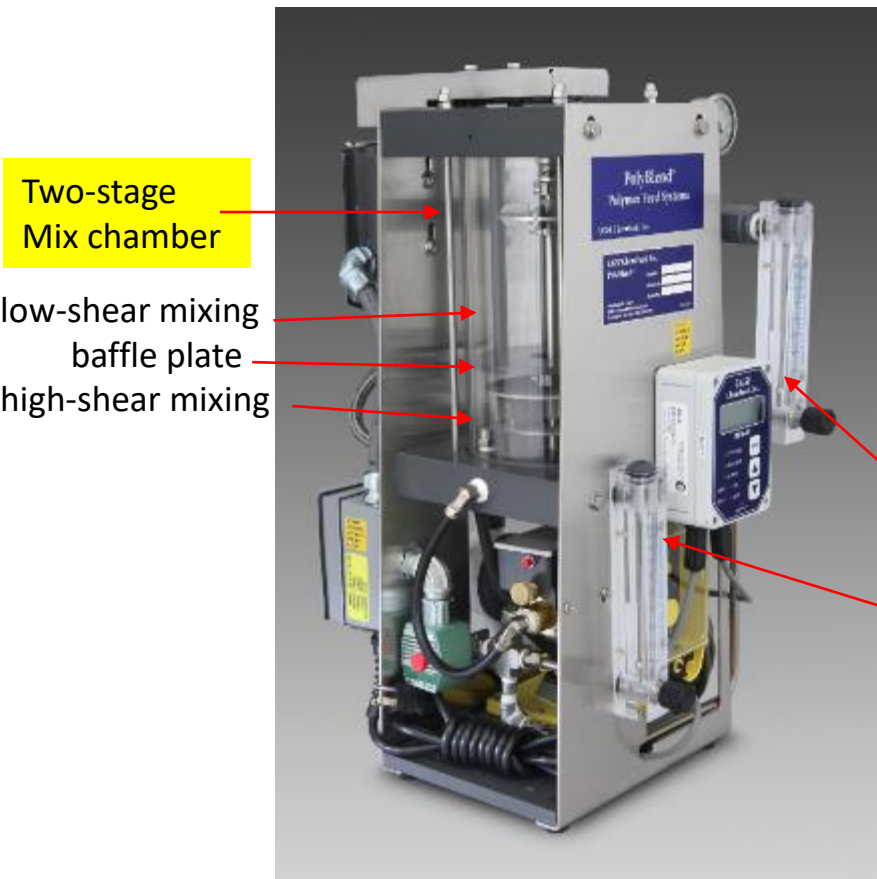
Case Study: Neshaminy Water Treatment Plant, PA

Polymer Usage of Two PolyBlend Systems

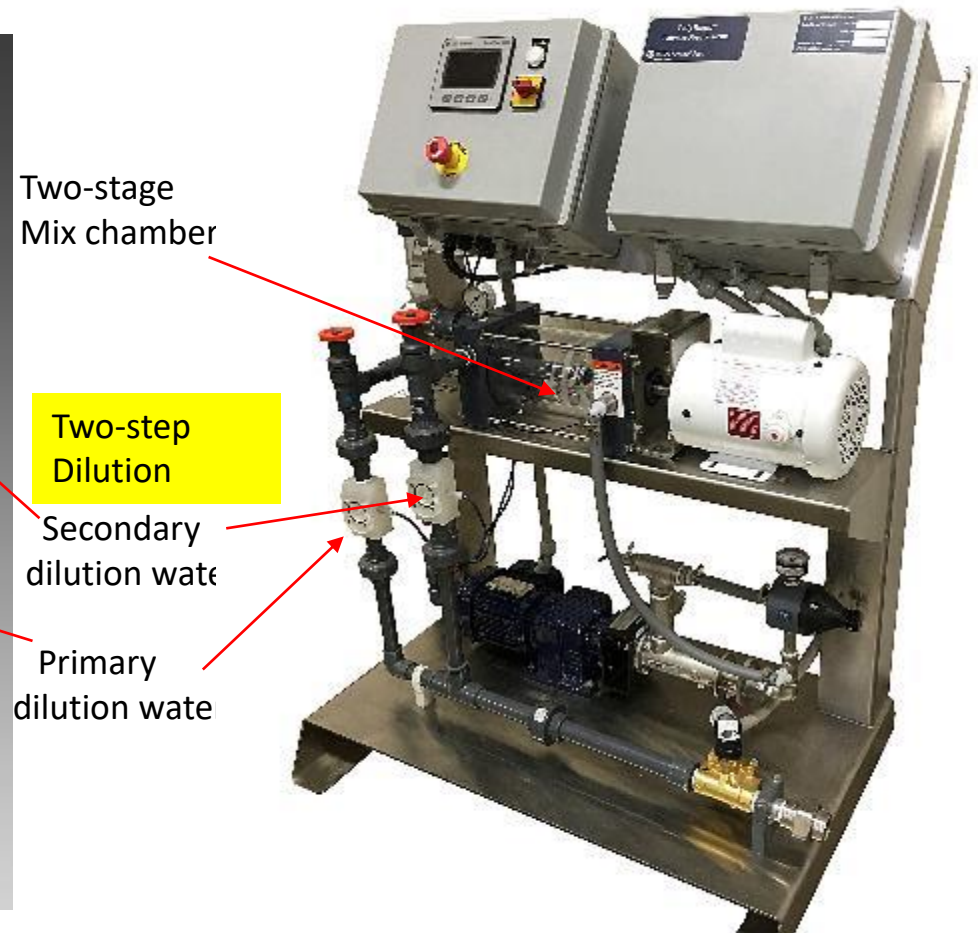


- Side-by-Side Trial from Feb to May 2016
- ***Polymer savings 30%***
- ***Sludge throughput increased by 15%***
- ***Cake solids improved marginally***

Two-stage Mix Chamber + Two-step Dilution Skid



Compact PB-series



Open-Frame Magnum-series

PolyBlend® Dry Polymer System

Two-Stage Mixing

First Stage

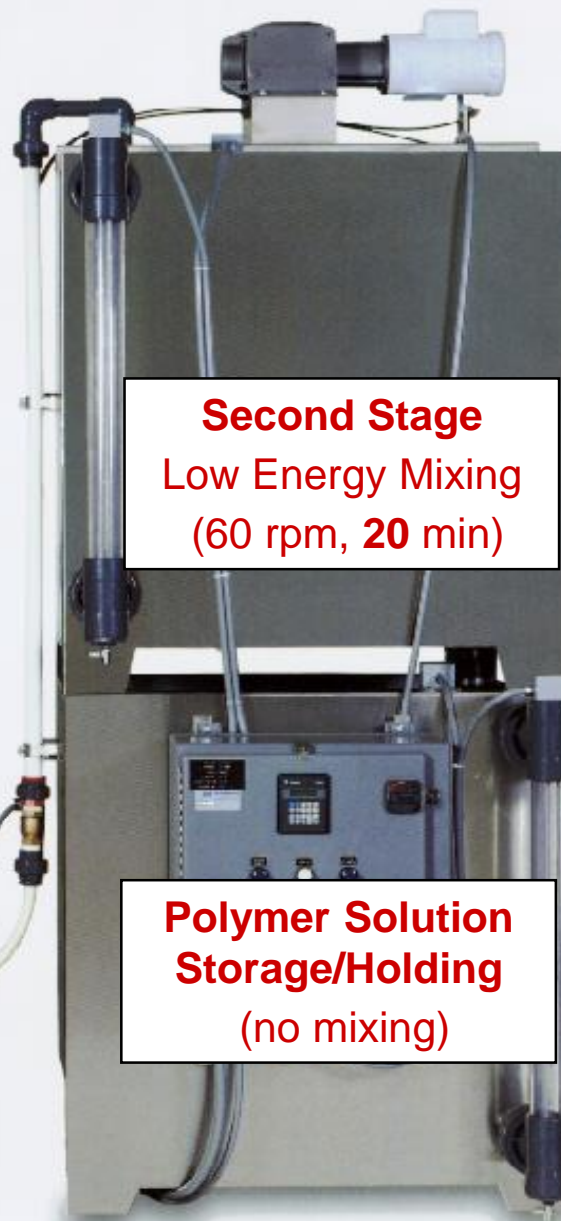
High Energy Mixing
(3,450 rpm, < 0.5 sec)



DD4 Disperser

Second Stage

Low Energy Mixing
(60 rpm, **20 min**)



**Polymer Solution
Storage/Holding**
(no mixing)

Mix and Hold Tanks

First-Stage of Dry Polymer Mixing: High Energy Initial Wetting

Very High-Energy Mixing for Short Time

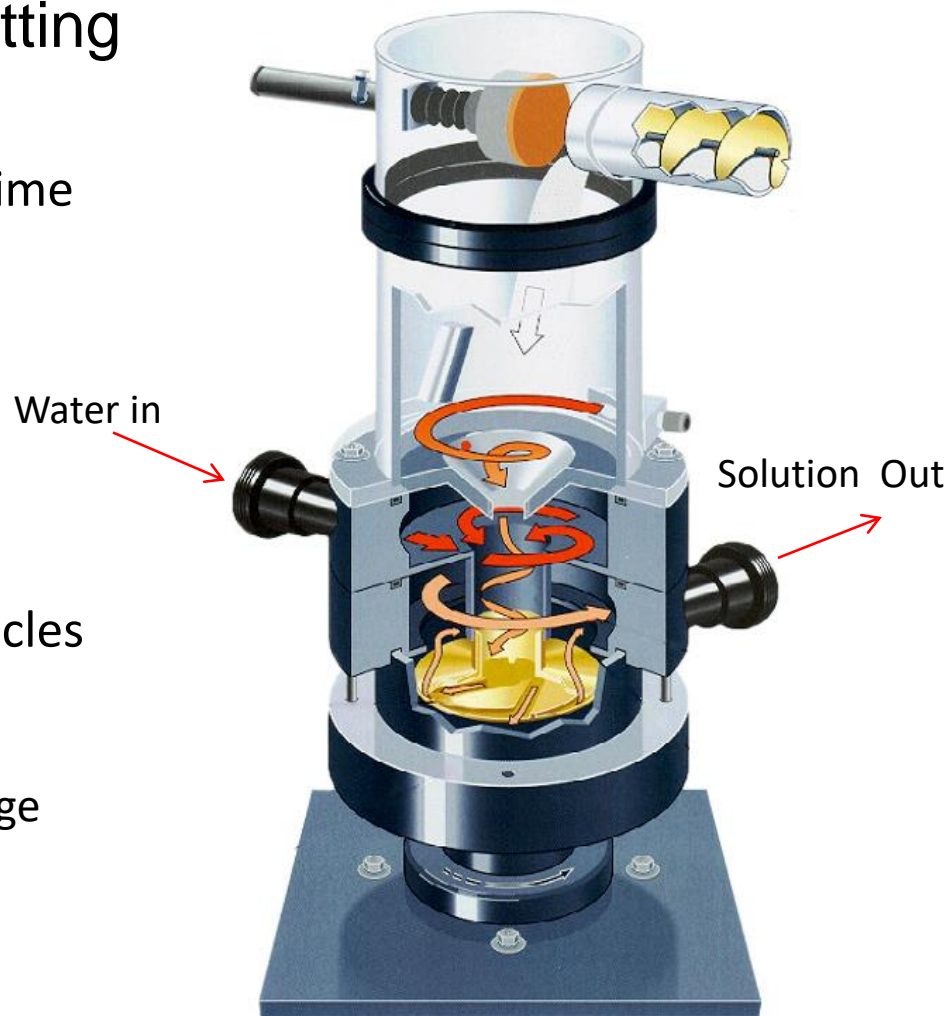
$$G = 15,000 \text{ sec}^{-1}$$

3,450 rpm for < 0.5 sec

Disperses Individual Polymer Particles

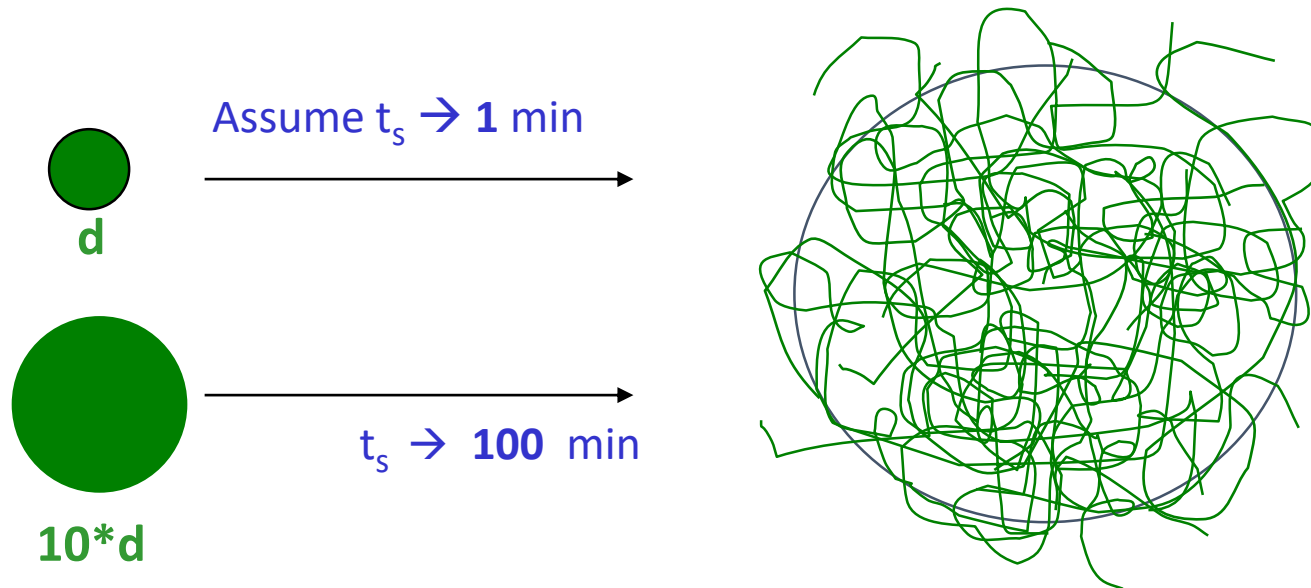
* **No Fisheye** Formation

* Shorter Mixing Time in Next Stage



Why Initial High-Energy Mixing is So Critical?

Polymer dissolution time, $t_s \sim (\text{diameter})^2$ Tanaka (1979)*



Initial high-energy mixing \rightarrow No fisheye formation \rightarrow Significantly shorter mixing time

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

Case Study: Dry Polymer Mixing System

Fairfield-Suisun Sewer District, CA

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



FKC screw press runs at average 70 gpm of sludge (2% solids content)

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: air blower → wetting head
- Mixing: two (2) 4,600 gal mix/age tanks
- 1 hour mixing and 4 - 8 hour aging time



UGSI PolyBlend Dry Polymer Demo System

- Initial wetting: high-energy mechanical mixing
- Mixing: two (2) 360 gal mix tanks
- 20 minute mixing, 10+ minute transfer time

Newly Installed FSSD Polymer System



Existing impeller

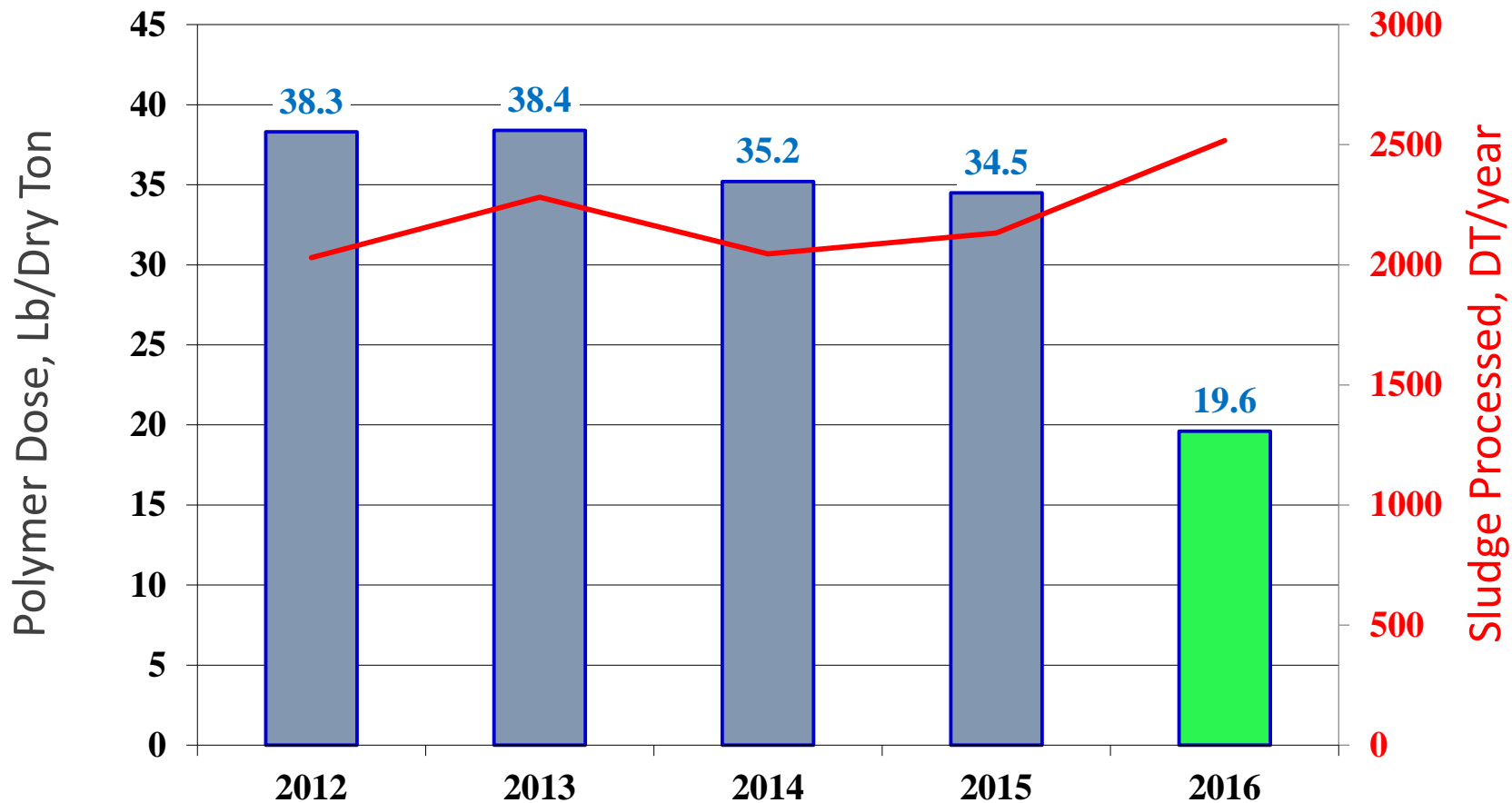
Old: Two 4,600 gal mixing/aging tanks
* 60 min mixing, 2-4 hour aging
New: Two 1,000 gal mixing tanks
* 30 min mixing, 15 min holding



Hollow wing impeller

FSSD Installed New PolyBlend[®] DP2000

Performance Data in 2016



**FSSD saved 42% on Screw Press Polymer in 2016
despite an increase in solids throughput by 18%**

Summary

- Good quality dilution water will yield to more efficient polymer solution.
- Emulsion polymer activation
 - Two-stage mixing: very high-energy mixing at initial wetting stage is critical to prevent fisheye formation, followed by low-energy mixing to minimize damaging polymer chain.
 - Sufficient residence time of low-energy mixing stage is required to achieve fully dissolved homogeneous solution.
 - Two-step dilution helps proper polymer activation by maximizing the value of breaker surfactant.
- Dry polymer activation
 - Very-high energy mixing at initial wetting stage is critical.
 - Low-speed and uniform mixing impeller that prevents Weissenberg effect should be used at the second stage mixing tank.

Thank You
Any Questions?

Visit Booth #408
YKim@ugsicorp.com

Polymer Application - where are polymers used?



Clarifier (coagulant-aid)

Filtration (filter-aid)

Drying Beds

Gravity Belt Thickener

Rotary Drum Thickener

Plate & Frame Press

Belt Filter Press

Screw Press

Centrifuge

Paper Industry

Cooling Tower (ZLD)

Mining & Metal Processing

Enhanced Oil Recovery



Mixing Tank for Dissolution of Dry Polymer

Patented Hollow-Wing Impeller

- No Weissenberg Effect

Large Impeller, **70%** of tank diameter

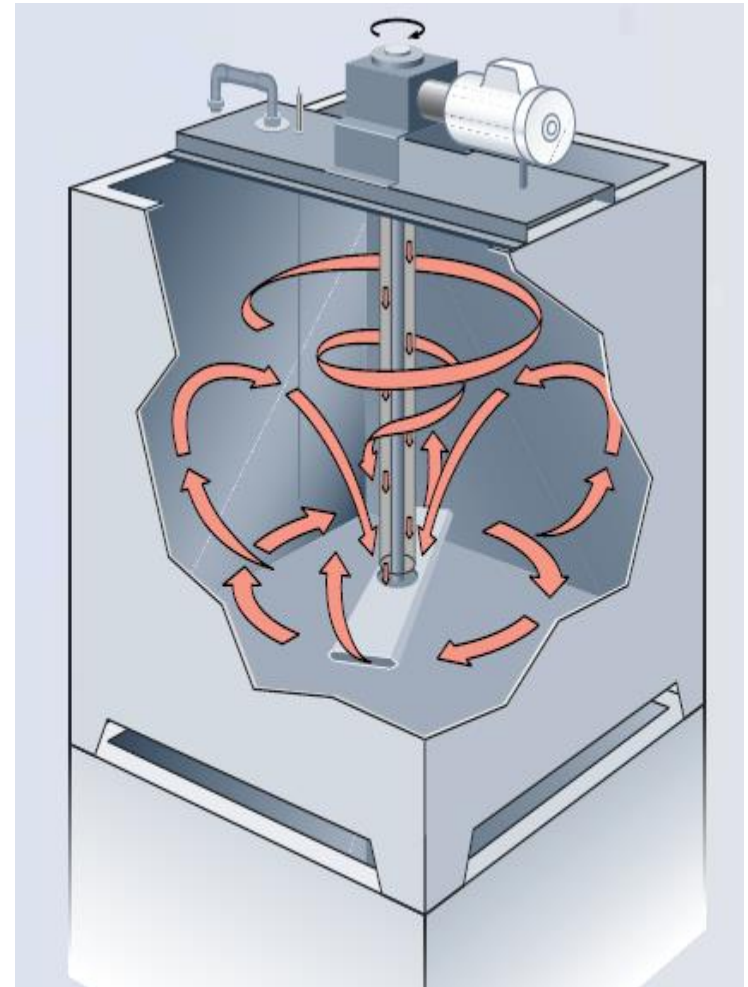
- **Uniform** Mixing Energy

Low RPM, 60 rpm

- **Low-intensity** Mixing
- Minimize Damage to Polymer Chain

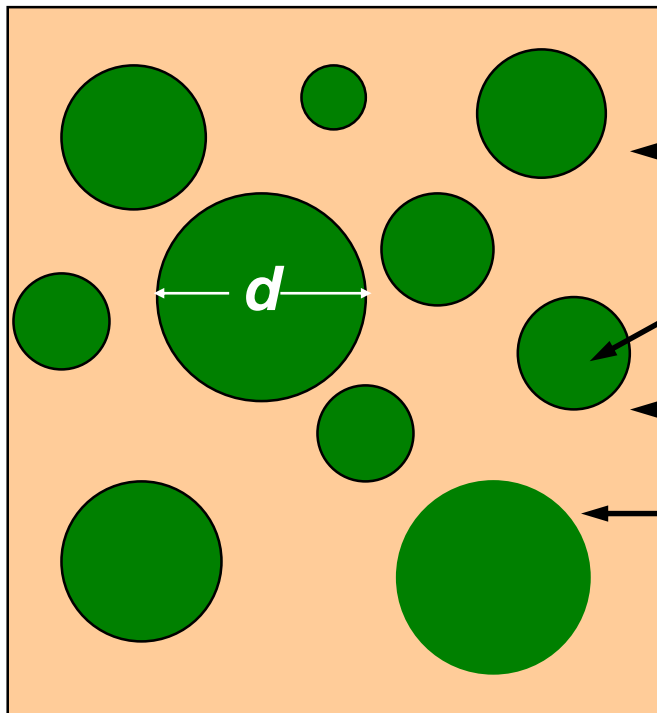
Shorter Mixing Time – Due to high energy DD4

- 20 - 30 min for Cationic Polymer
- 30 - 40 min for Anionic Polymer
- Short mixing time minimizes damage to polymer chain



Two-Step Dilution: Why Primary Mixing at High %?

Inverting Surfactant helps to “invert (or break)” stable emulsion state



$d = 0.1 - 2 \mu\text{m}$

Hydrocarbon Oil: 30%

Polymer Gel: Polymer 40%

Water 30%

Stabilizing surfactant

Inverting (breaker) surfactant

- Strip off oil from polymer gels
- Break and disperse oil into micron-sized entities

To enable inverting surfactant to work properly,
make polymer solution at high concentration*

* 1.0% - 1.25% primary mixing in mix chamber

* 0.25% - 0.5% secondary mixing (dilution)

* AWWA Standard for Polyacrylamide (ANSI-AWWA B453-06), 11, 2006

Facts about Aging

Aging may help:

- * Very high molecular weight, low charge density (nonionic) polymers, or
- * Poor initial wetting by low mixing energy

Aging does not help:

- * Medium to high molecular weight, high charge density polymers, or
- * Initial wetting by very-high mixing energy

Aging may hurt:

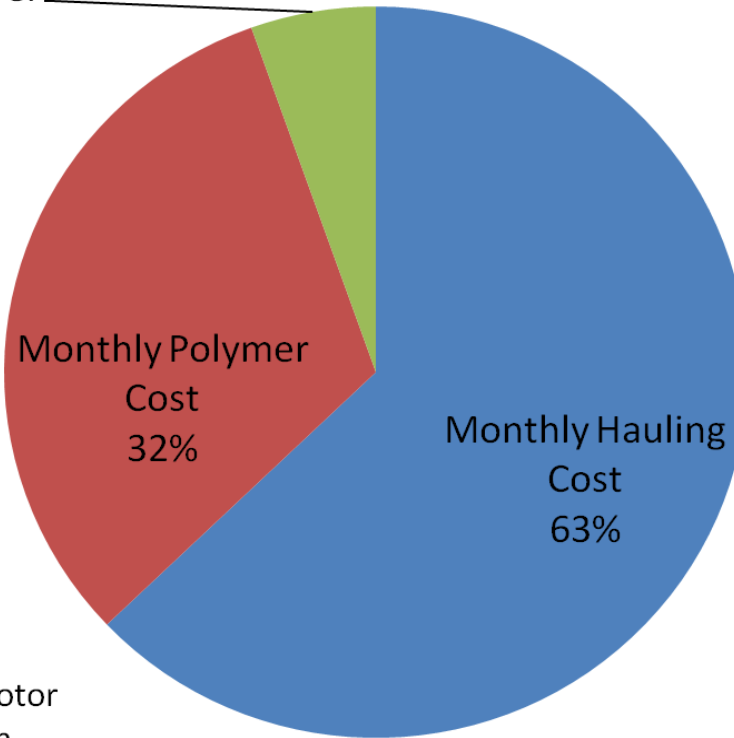
- * Bad quality or reclaimed water for polymer mixing, or
- * Low concentration of polymer solution, or
- * Too long aging time

Dewatering Cost at EMWD: \$3.7M / year

Polymer Cost: Average \$1.2 M / year

**Average Monthly Dewatering Cost Breakdown - District-wide
(Hauling, Polymer, Power est.)**

Monthly Power
Cost
5%



Hauling:
4,275 wet tons/month
51,300 wet tons/yr

Average Monthly Costs:
* \$194,000 Hauling
* \$98,000 Polymer
* \$17,000 Power
* \$309,000 Total

Basis:

- * \$45.73/WT Hauling
- * \$1.24/lb Polymer
- * \$0.14/kW-hr and 100% of motor nameplate power consumption
- * 7 day/wk; 8 hrs/day operation

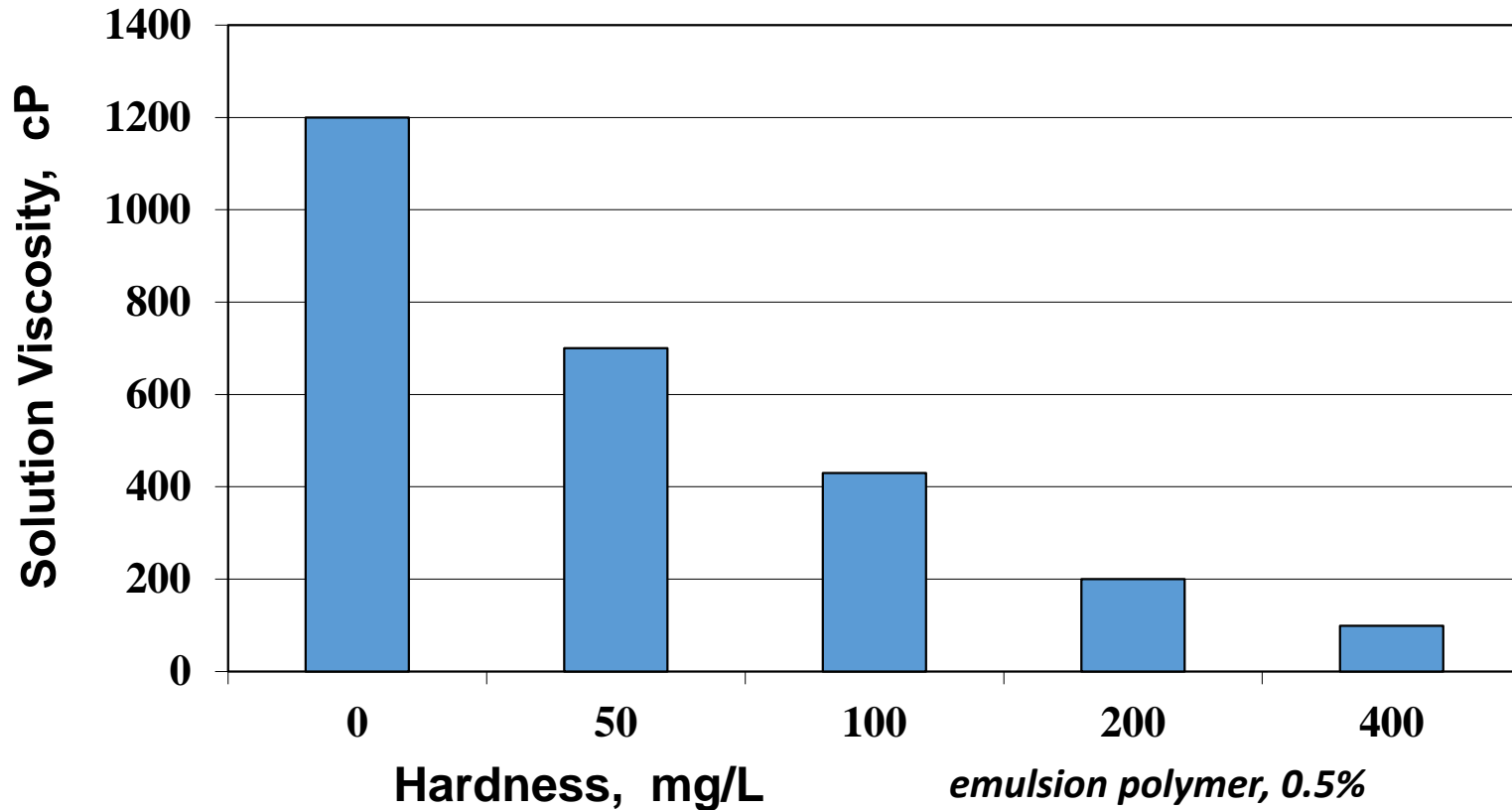
Annual Average Dewatering Cost (2011-2014) = \$3.7M

Anything you may recommend?



Effect of Dilution Water Hardness

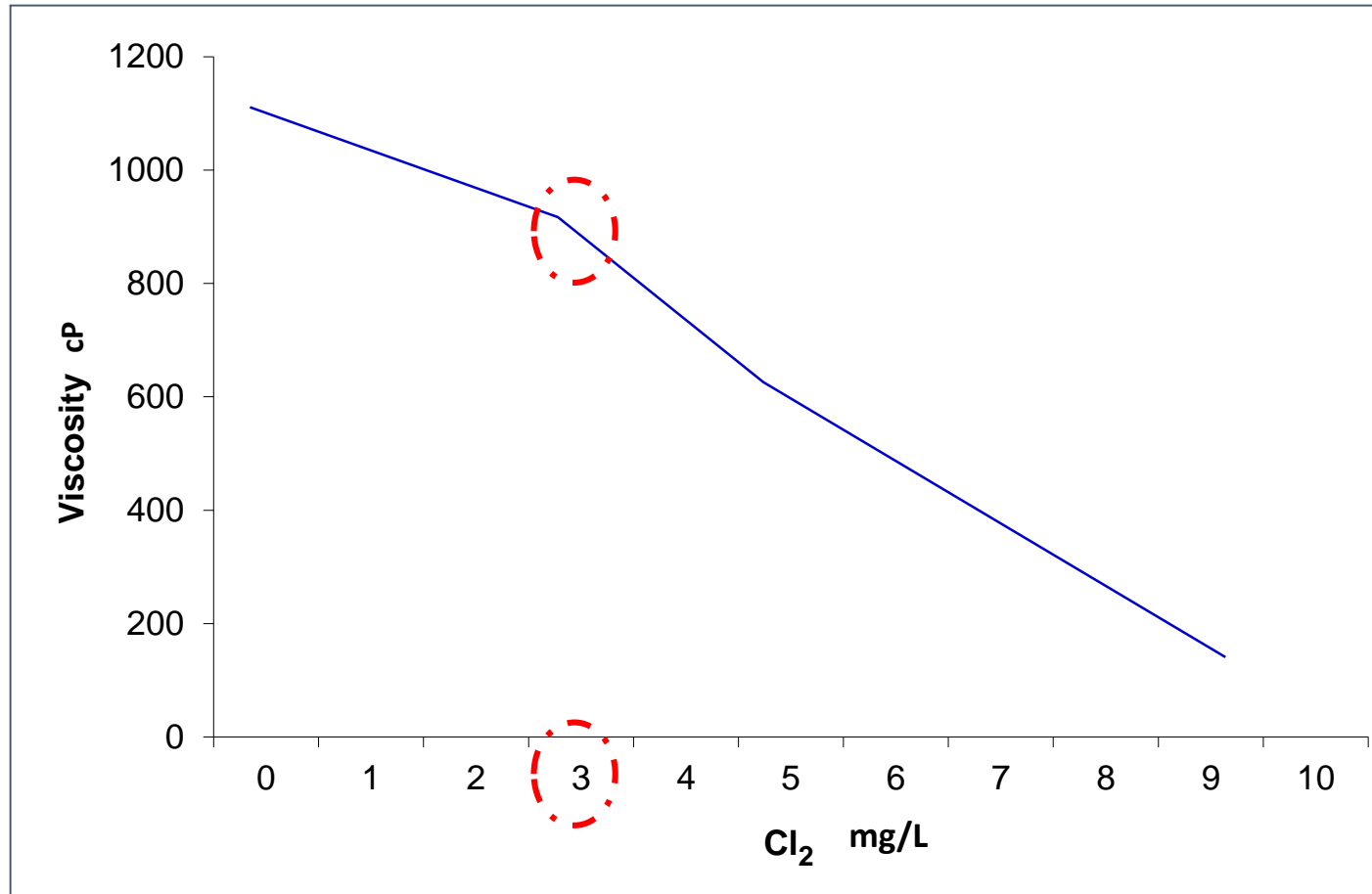
Soft water helps polymer chains to be fully extended



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

Effect of Dilution Water **Chlorine Content**

When reclaimed water used for polymer mixing, chlorine < 3 mg/L

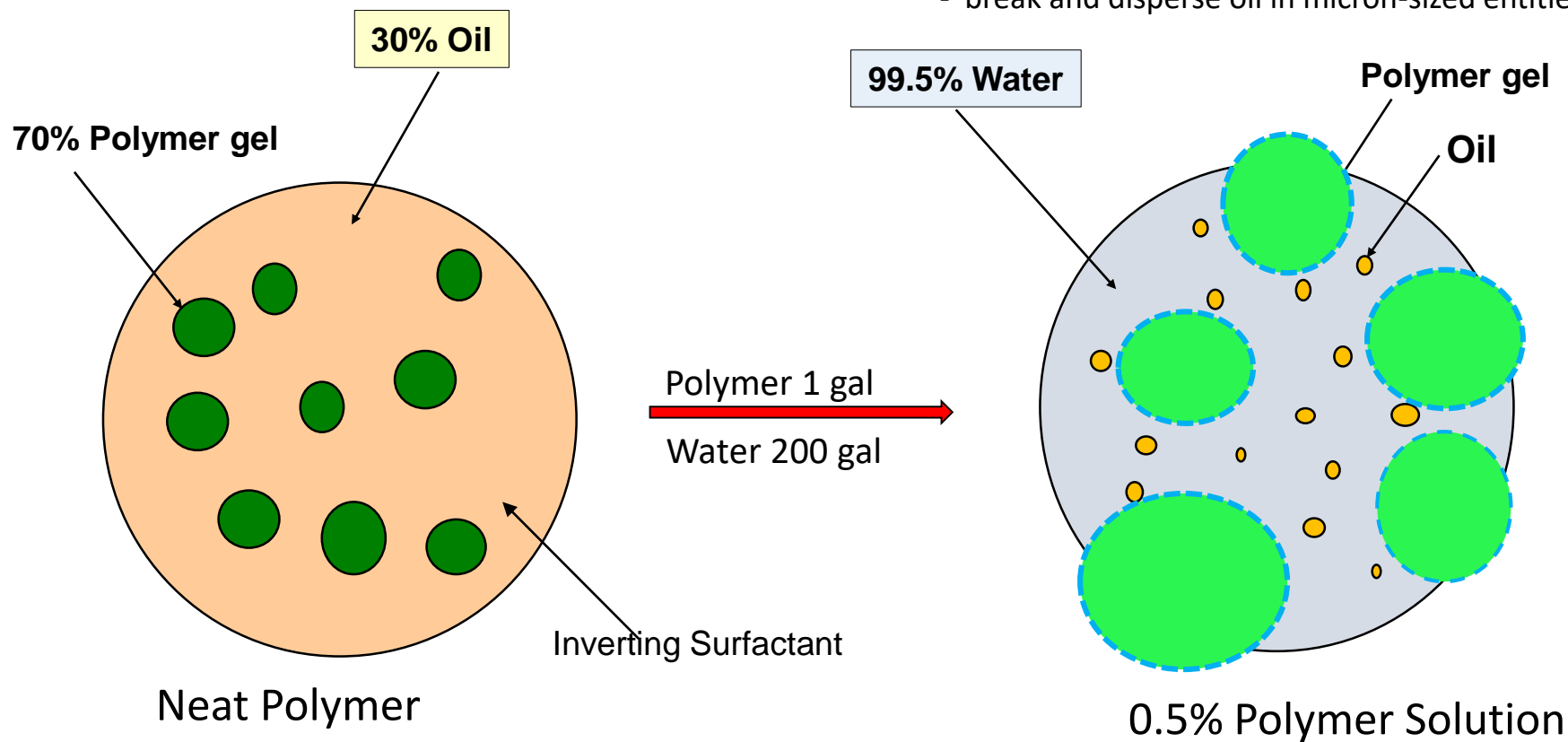


Inversion of Emulsion: water-in-oil → oil-in-water

Inverting Surfactant

Strip “oil” off the polymer surface

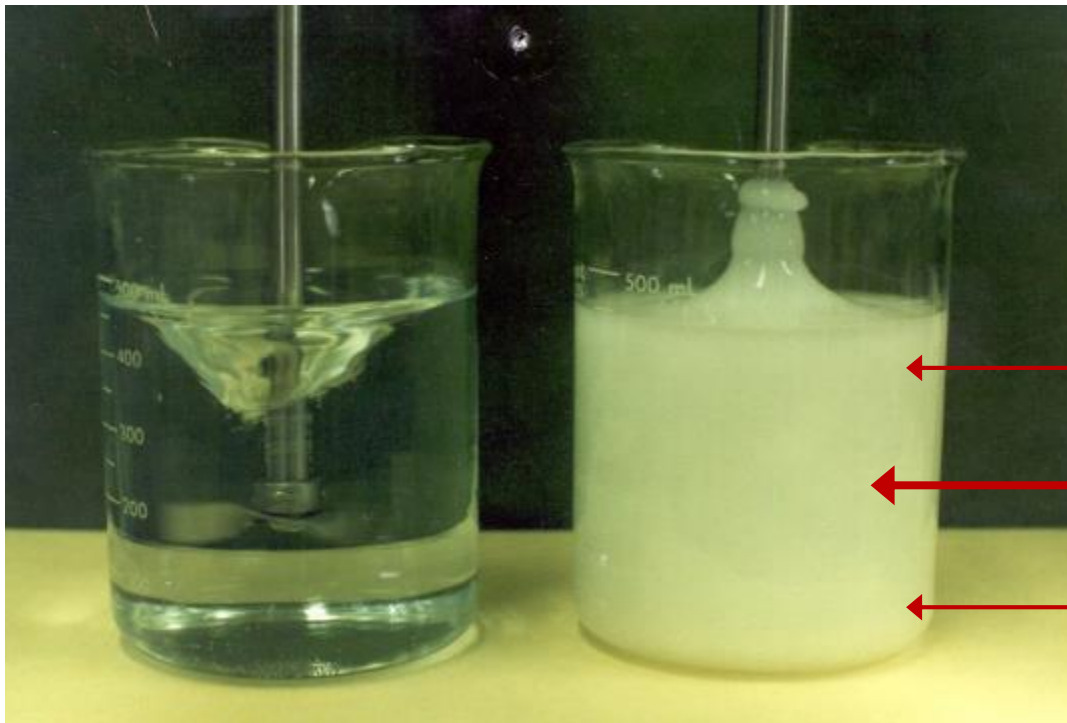
- help polymer get exposed to water quickly
- break and disperse oil in micron-sized entities



Especially Important for Clarifier at WTP

Weissenberg Effect (undesired) in Polymer Mixing

- * Polymer solution exceeding “critical concentration” climbs up mixing shaft
- * Extremely non-uniform mixing
- * Critical factor for “conventional” polymer mix tank → max 0.2% limit for HMW polymer



Water
(Newtonian)

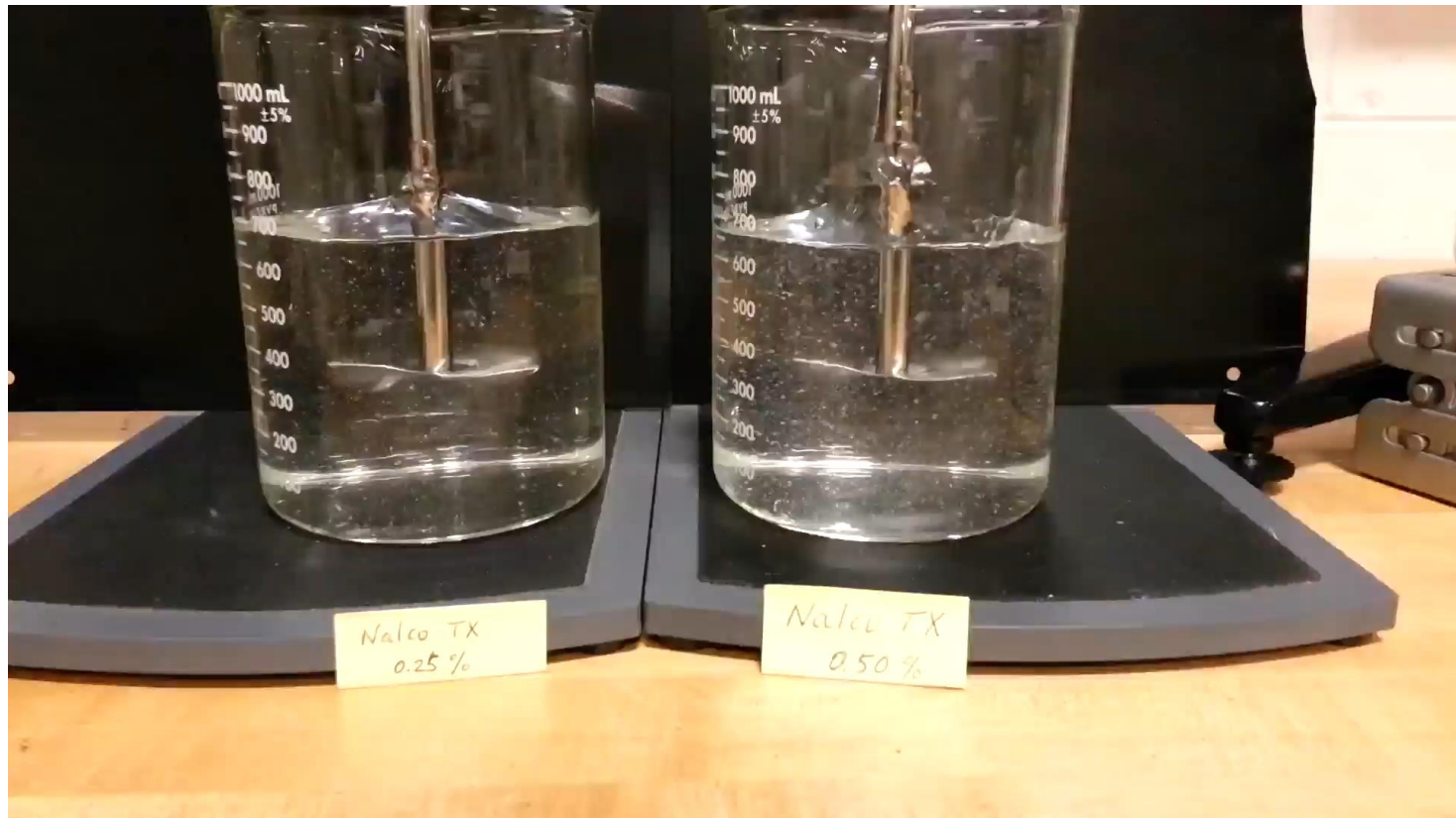
Polymer Solution
(Non-Newtonian, Pseudoplastic)

← extremely low mixing

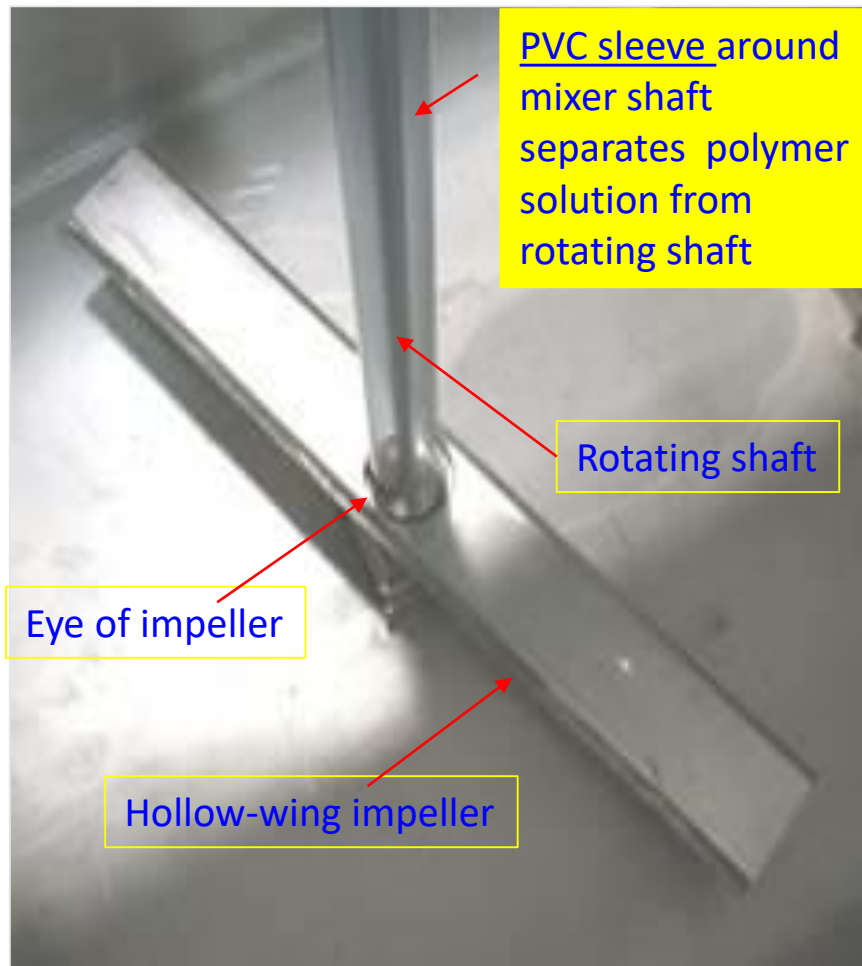
← very high mixing

← extremely low mixing

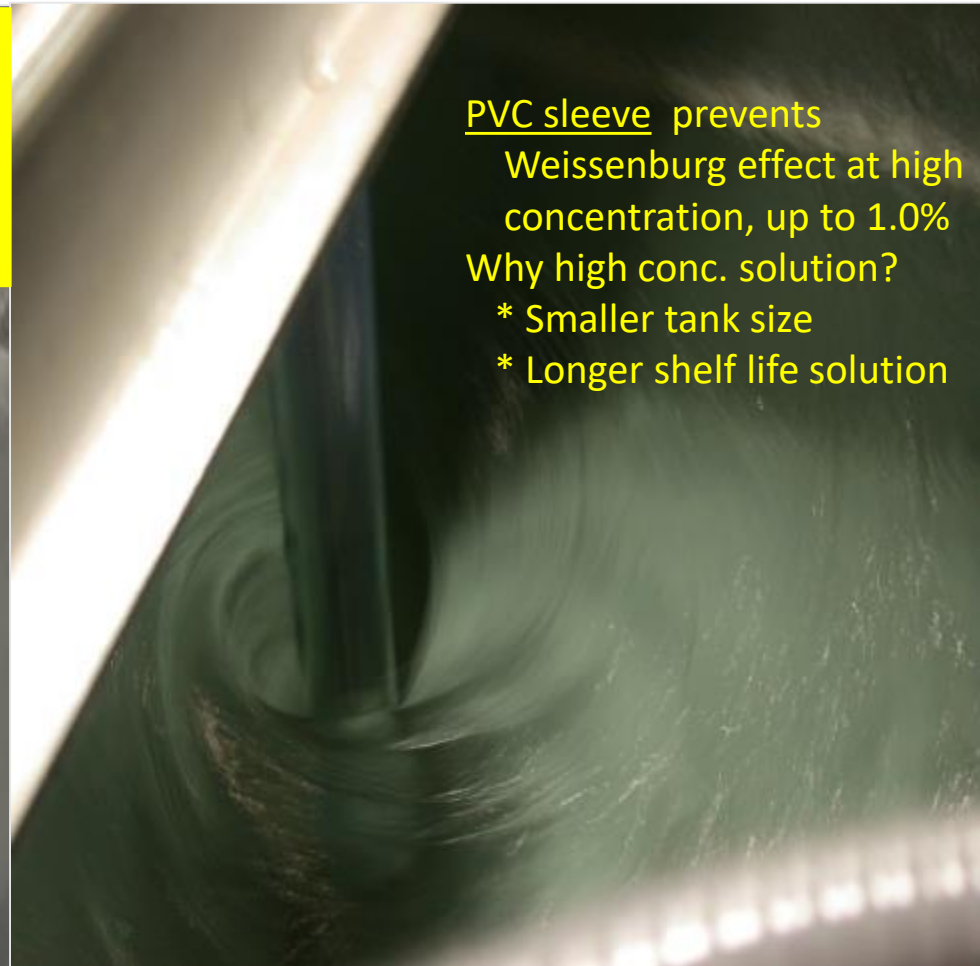
Notice polymer solution is “climbing” up the mixer shaft
(30 min after mixing (Nalco TX13182): 0.25%, 0.50%)



Polymer Mixing Tank With No Weissenberg Effect



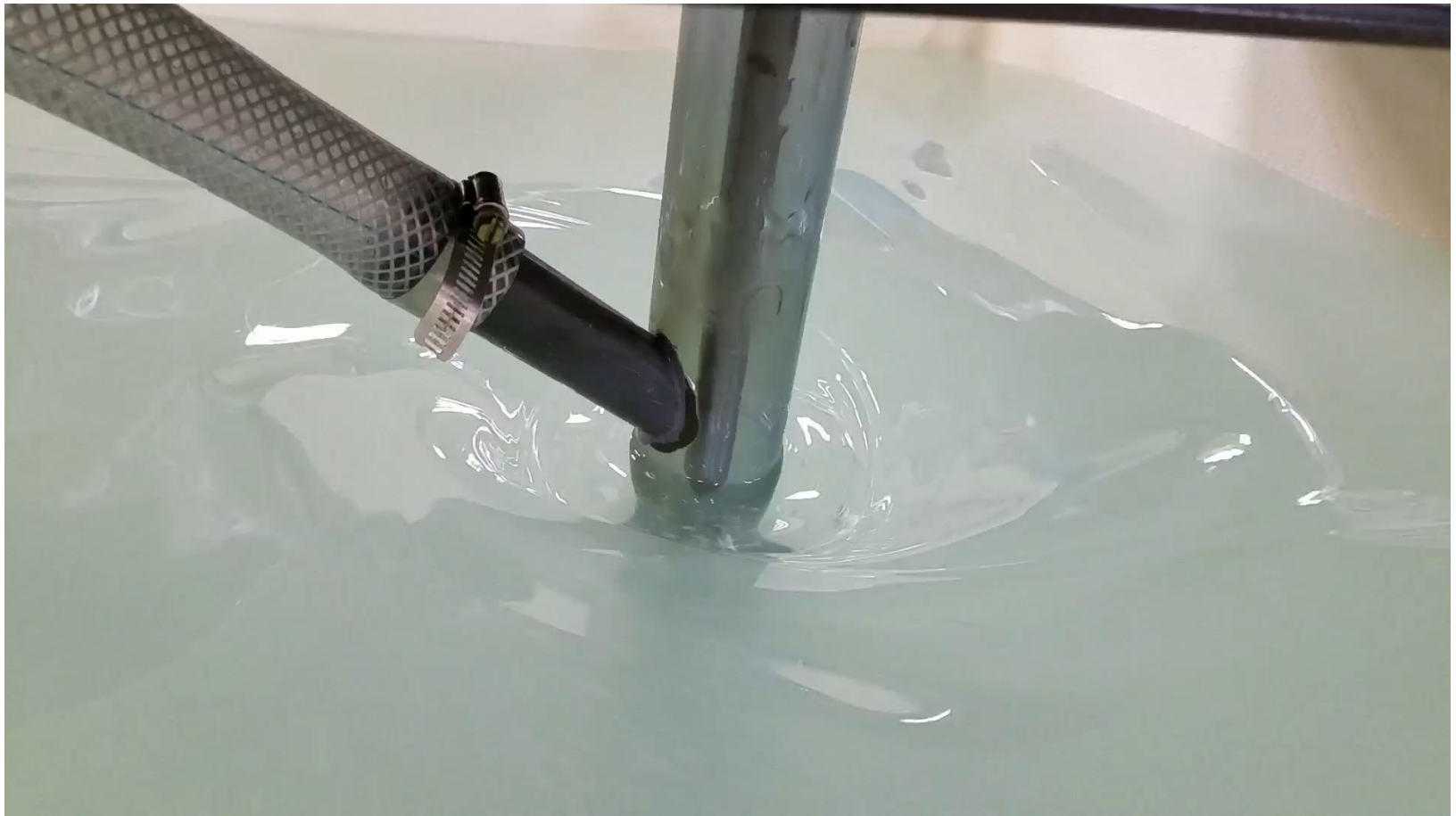
Impeller / tank diameter > 0.7



Cationic Polymer Solution @ 0.75%

Polymer Mixing Tank With No Weissenberg Effect

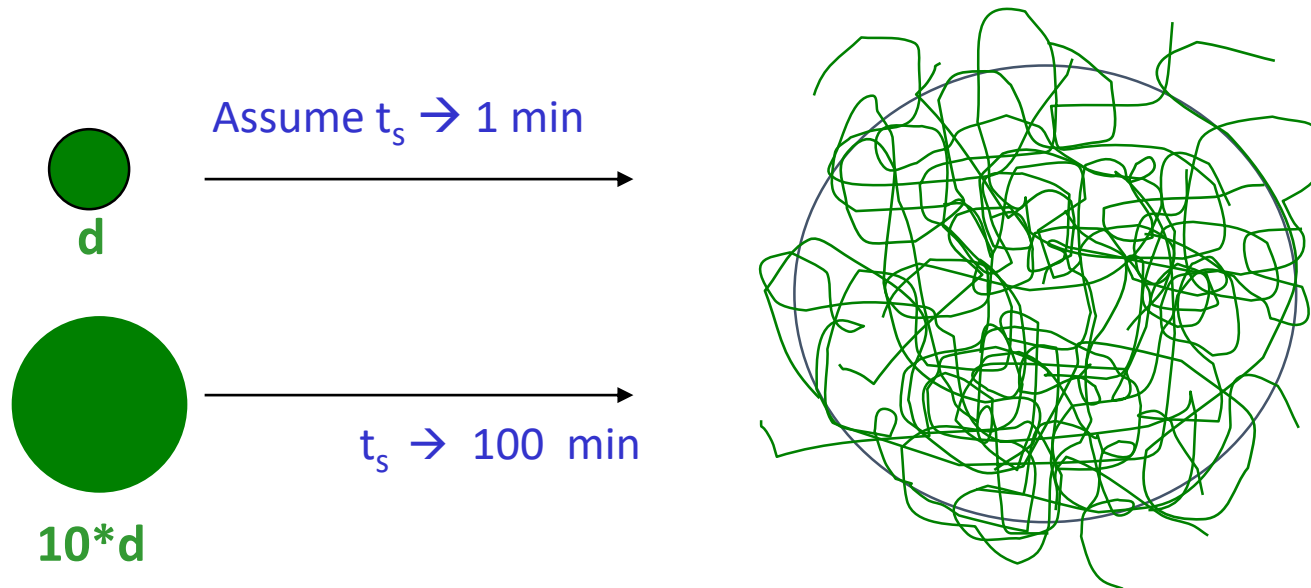
(30 min mixing, Clarifloc C-3289: 0.65%, 2,710 cP)



How to Achieve this Result?

initial high-energy mixing is critical

Polymer dissolution time, $t_s \sim (\text{diameter})^2$ Tanaka (1979)*



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

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

Handling and Storage

Shelf Life:

- Emulsion: 6 months, unopened drum/tote
- Dry: up to 3 years, unopened bag

Storage Temperature: 50 - 80 F

- Do not allow emulsion to freeze
- Once frozen, thaw in heated area and mix well

Handling

- Wear latex gloves and eye protection
- Minimize exposing to air, avoid dusting (dry)
- Don't try to clean spilled polymer with water
- Always consult MSDS

Polymer science dictates the most effective way of activating polymers- polymer activation equipment should follow:

