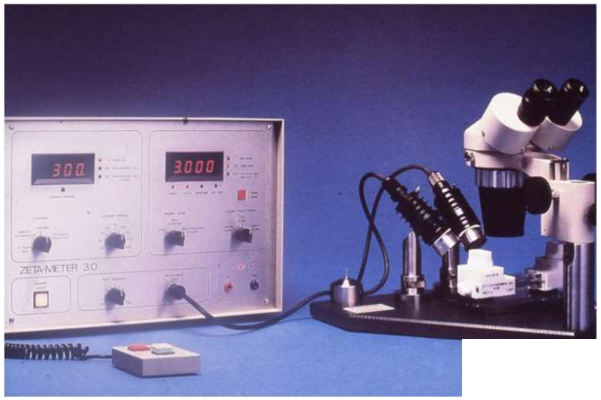
Coagulation Evaluation Tools



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2025

Flocculation

Mixing requires energy input!

Number of collisions depends on:

a) Mixing energy

b) Detention time

– In water treatment, mixing intensity is referred to as the velocity gradient, or *G*-value:

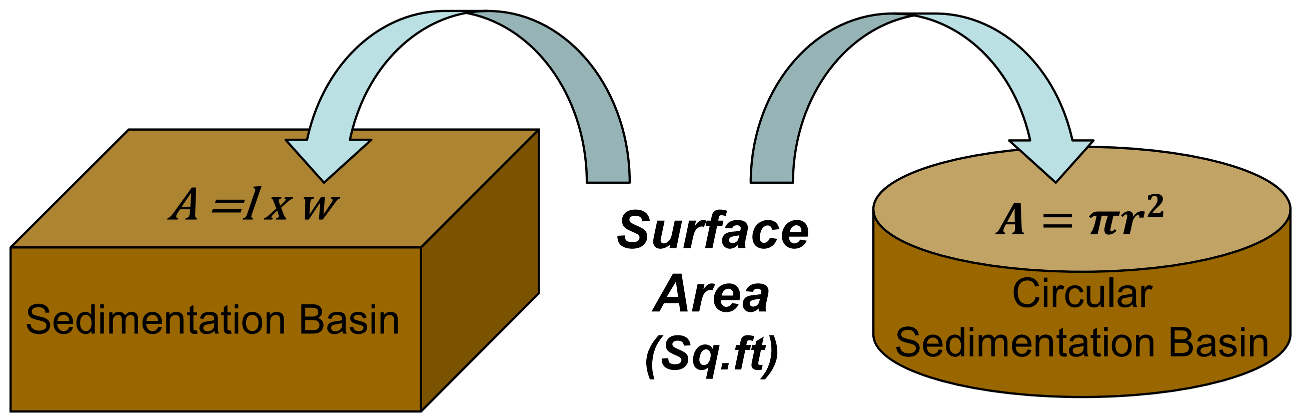
$$G = \sqrt{\frac{Dissipated\ Power}{(viscosity)\times(Volume\ of\ tank)}}\ \text{, units of}\ \frac{1}{sec}\ \ (\text{or } sec^{-1})$$

Surface Loading Rate

Incoming Flow

(expressed as)

- ***MGD***
- ***gpm***
- ***cfm***



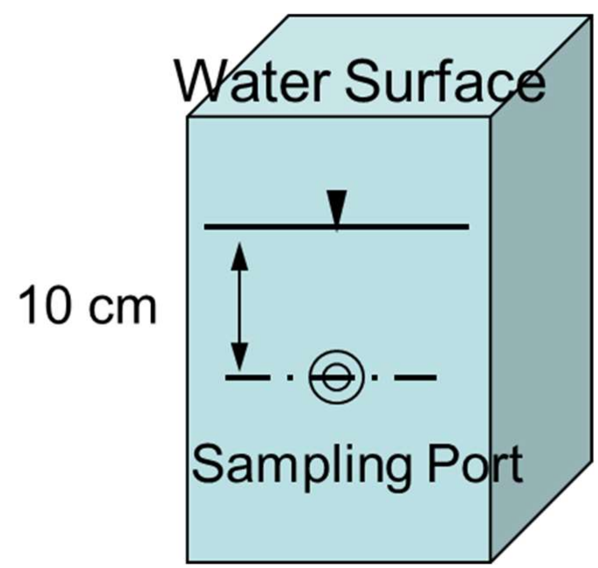
1. ***Divide flow (gpm) by area (sq.ft) = gpm/sq.ft***

   Surface Loading Rate = Overflow Rate

2. ***Divide flow (cu.ft/min) by area (sq.ft) = ft / min***

   Liquid Velocity = (V_o)

- ***Convert feet to centimeters (cm) = cm /min***



Credits

- John Hanchak, Sr.
- Zeta-Meter, Inc.
- Malvern Panalytical
- Dr. Bill Knocke, VT

Also draw heavily from:

- AWWA Water Supply Operations texts
- AWWA Manual of Water Supply Practices, M37

Ten Common Problems in Treatment

→ 1. No (or inadequate) coagulant control strategy
2. Inadequate rapid mix
3. Lack of individual filter effluent monitoring
4. Inadequate or no filter-to-waste
5. Turbidimeters not calibrated
→ 6. Improper chemical doses
7. Inadequate operation and maintenance
8. Starting up dirty filters
→ 9. Inadequate process monitoring
10. Filter Run Time as only criterion for backwashing

Coagulation Evaluation Tools

- Jar Tests
- Zeta Meter
- Streaming Current Monitor
- UV_{254}/TOC/Specific Ultraviolet Absorbance
- Trends (turbidity, headloss, particle counts)

JAR TESTS

<u>Jar testing</u> is the most economical and most common tool for evaluating the coagulation process for a water treatment plant. (Water Operator Certification Exam Prep p. 101)

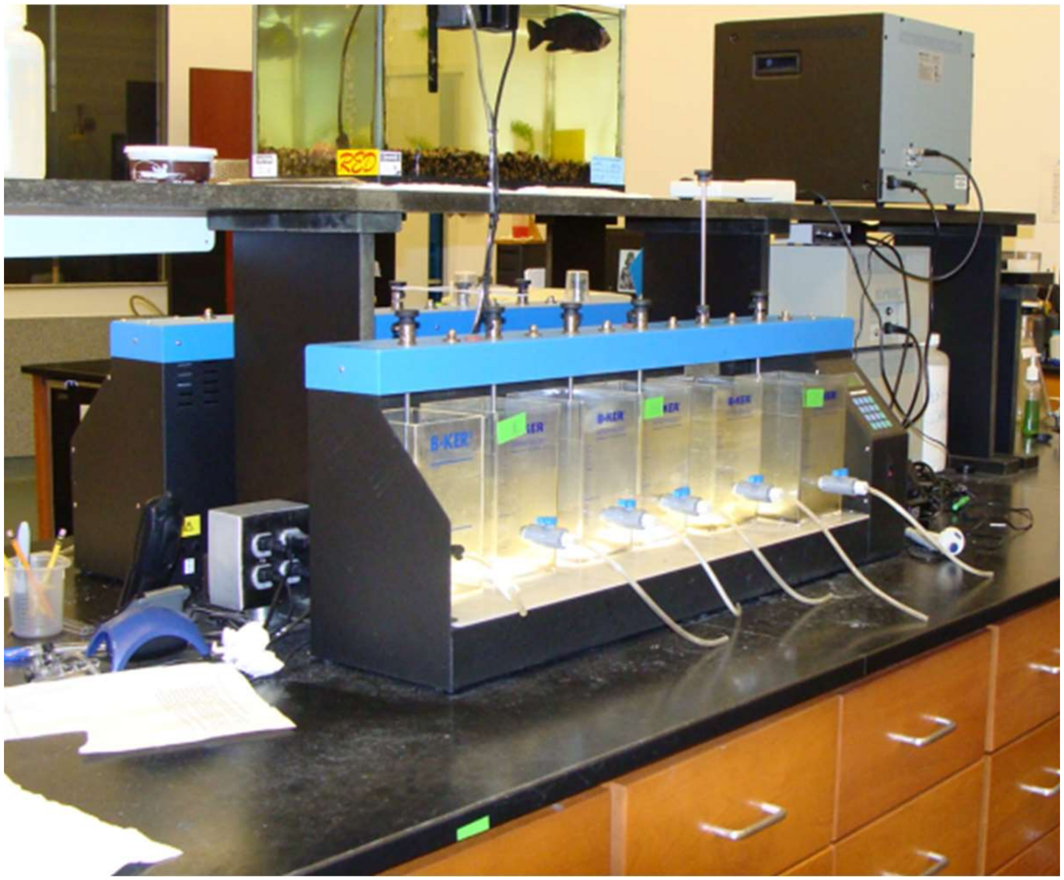
JAR TESTS

Jar Testing is a means of simulating conventional treatment steps that occur in the full-scale plant at a bench-scale….

For the purpose of evaluating:

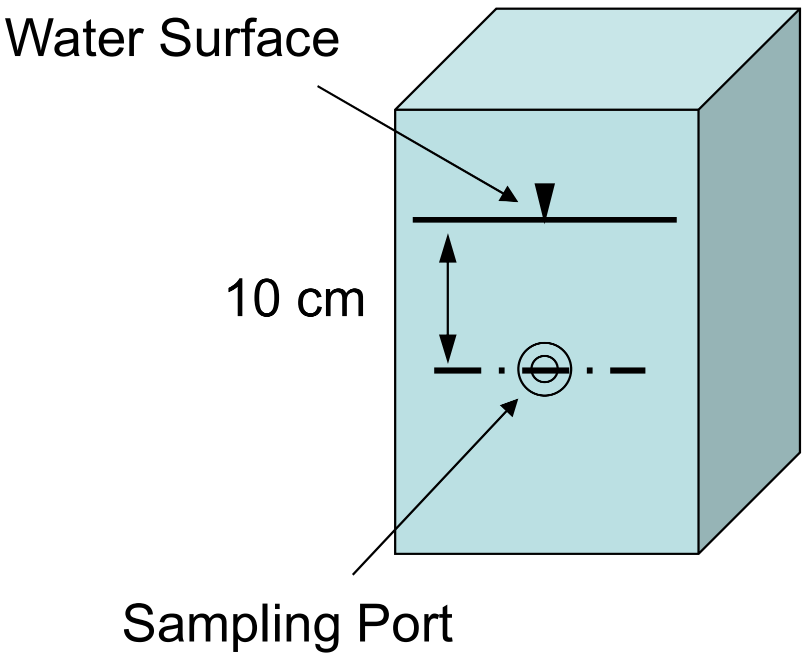
1) changes in chemical doses or points of application
2) alternative coagulants and/or coagulant aids
3) alternative pre-oxidation strategies
4) variations in mixing intensities, detention times, or loading rates

"Standard" 6 Jar – Tester



- Allows for multiple evaluations to be performed simultaneously
- Provides visual observation of floc development
- Can be used to simulate plant operating characteristics

JAR TESTS



Floc Wagner Jars

- 4.5 inches – square top
- 2 liter capacity
- Sampling port located 10 cm below water level

My WTP doesn't look anything like this jar!

JAR TESTS (MIXING CONDITIONS)

- Mixing makes a difference – both rapid mix and flocculation
  - → Mixing intensity (velocity gradient),
  - → Detention time

# of collisions depends on ***Gt***

- **Both should match the full-scale as much as possible (if trying to mimic full-scale)**

❖ Especially if time dependent reactions such as oxidation with permanganate are being evaluated

JAR TESTS (SETTLING CONDITIONS)

Jars ***do not*** mimic full-scale!

What about detention time? 1 – 2 hrs?

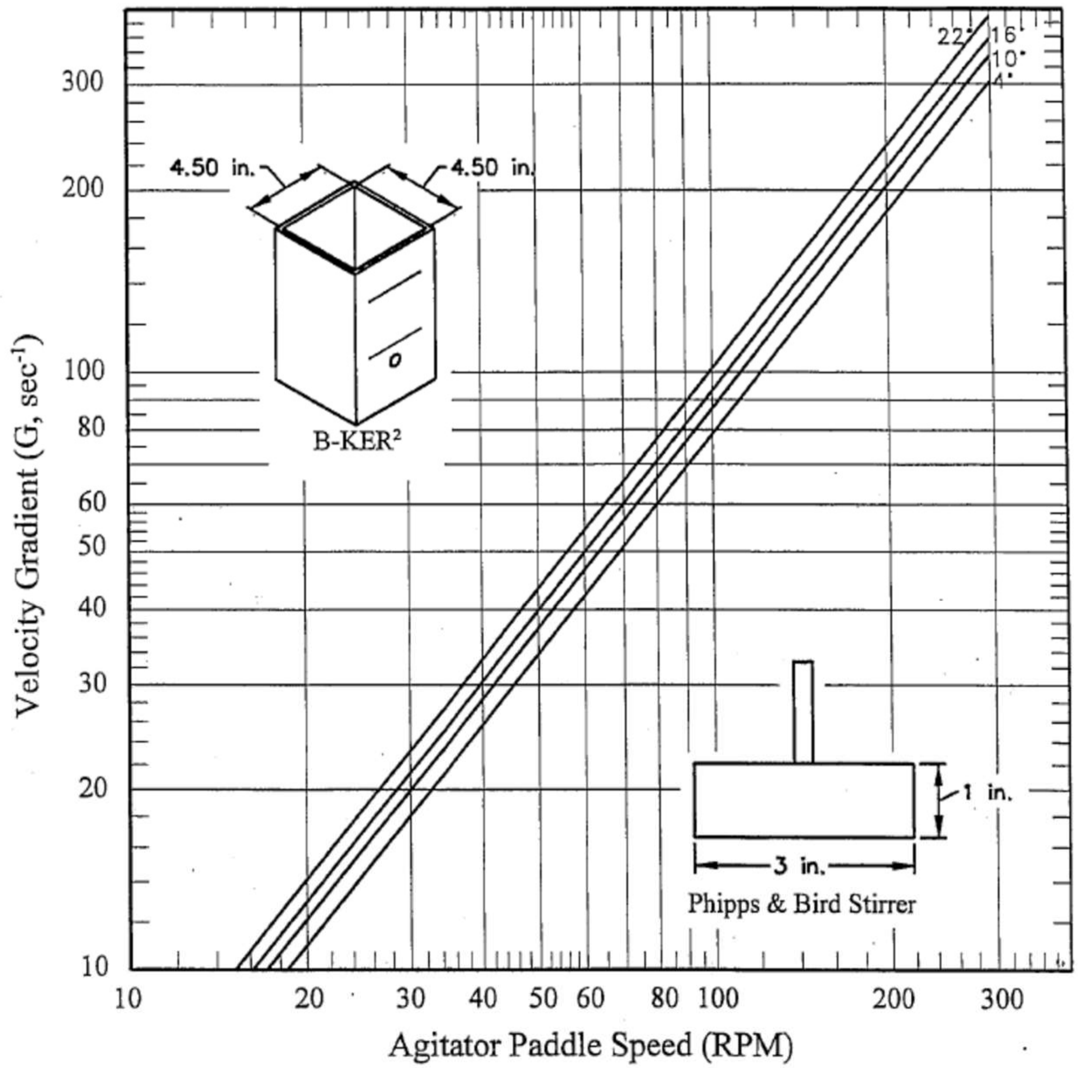
To evaluate sedimentation in a jar, we need to consider the loading rate (overflow rate) of the full-scale basins, not the detention time!

→Particle removal in sedimentation basins depends on individual particle **settling velocities**.

JAR TEST: Velocity gradient, G

Q: How know if mixing intensity in jar matches full-scale basins?

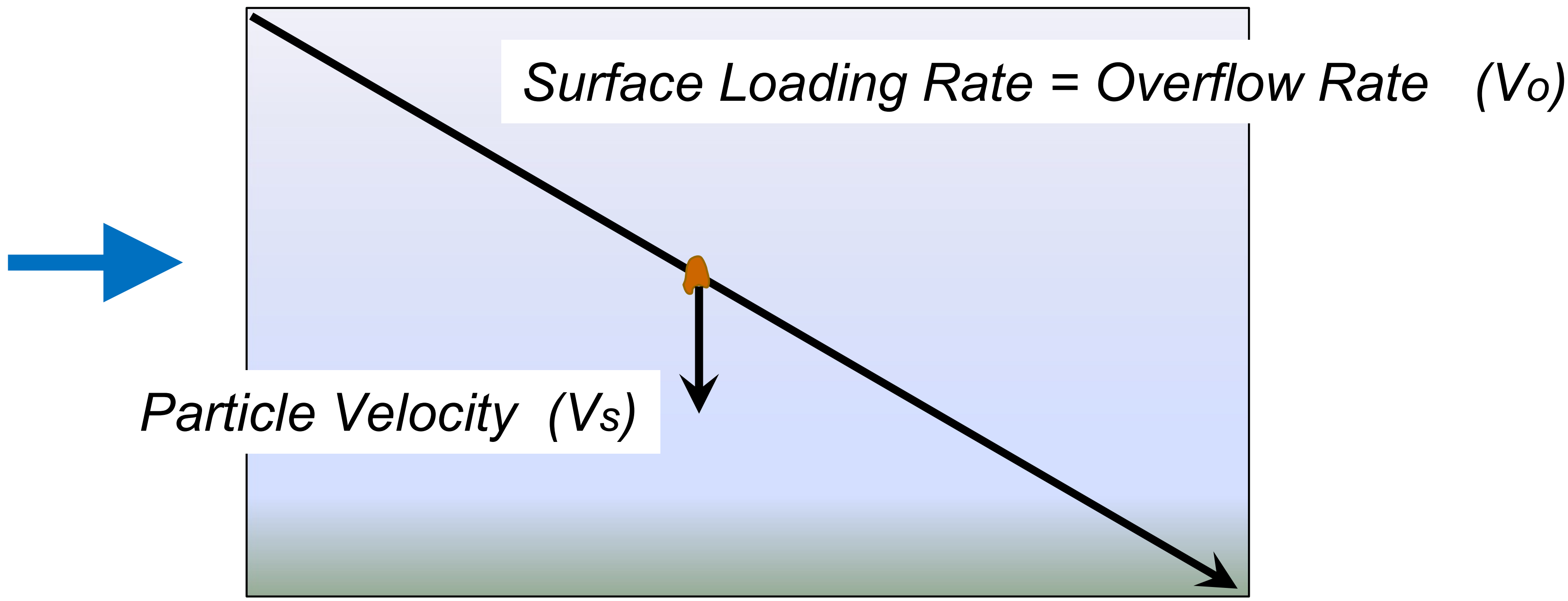
Need similar velocity gradients



Velocity Gradient vs. Agitator Speed for a 2-liter Square Beaker (B-KER²), Using a Phipps & Bird Stirrer. Water samples are at various temperatures (C°).

Settling Velocity

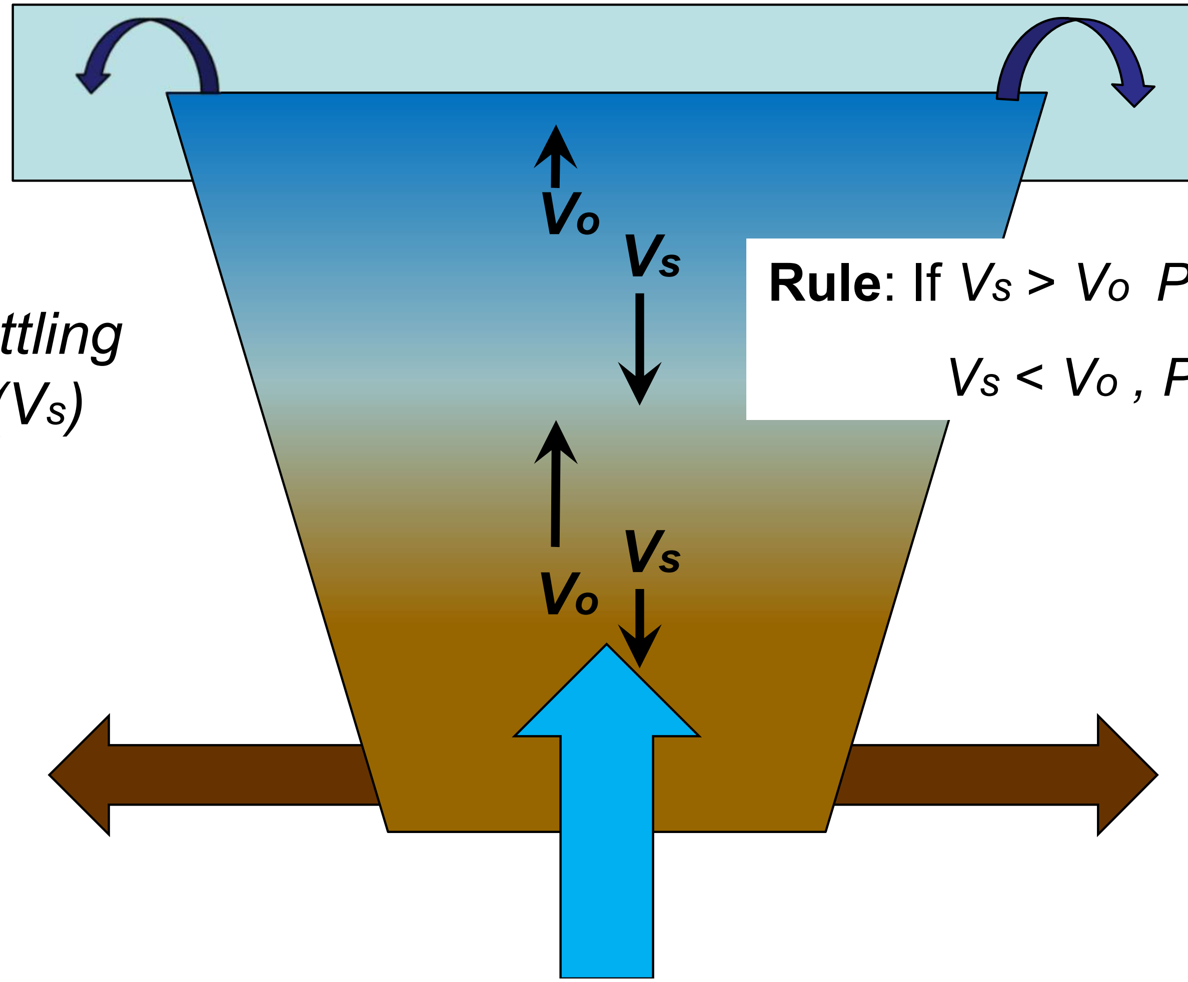
- Settling velocity depends on <u>particle density</u> and <u>size</u> (and temperature/viscosity)



General Rule: If *Vs* $\geq$ *Vo , then Particles are "Captured"*

Vs < Vo , then Particles "Escape"

Surface Loading Rate: Upflow Clarifier



Particle Settling Velocity = (V_s)

Rule: If $V_s > V_o$ Particles ***Settle***

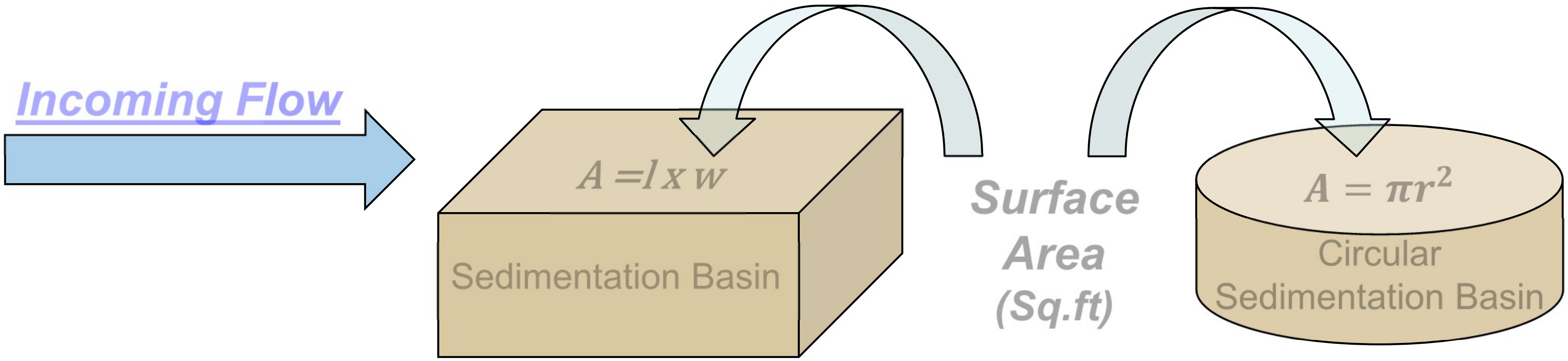
$V_s < V_o$, Particles ***Rise***

Settled Solids

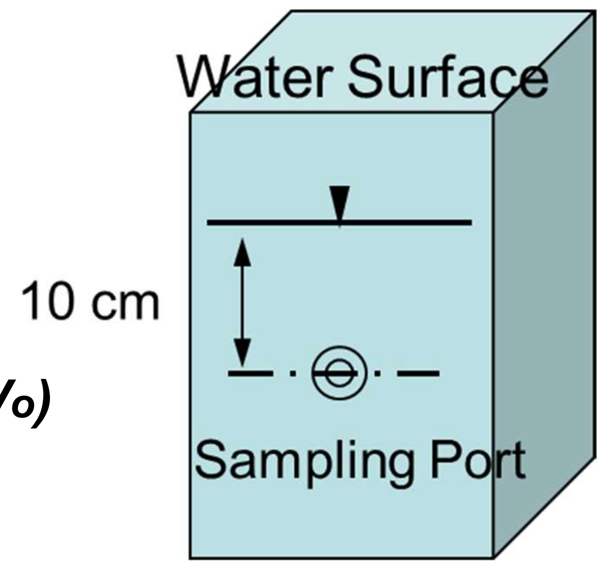
Liquid flow Rate = Overflow Rate (V_o)

(Surface Loading Rate)

Developing a Settling Velocity Graph



- ***Select Sample time (1, 4, 10) minute***
- ***10 cm Port (distance) divided by***
  Sample time = cm/min (example: 10cm/10 min)
  = 1 cm/min (Particle Settling Velocity) = (V_s)



Turbidity Value represents (V_s)
Therefore Turbidity Value (V_s) @ Overflow Rate (V_o)

Plot Turbidity Value (Sample) vs. Settling Velocity

JAR TESTS

<u>What do we measure?</u>

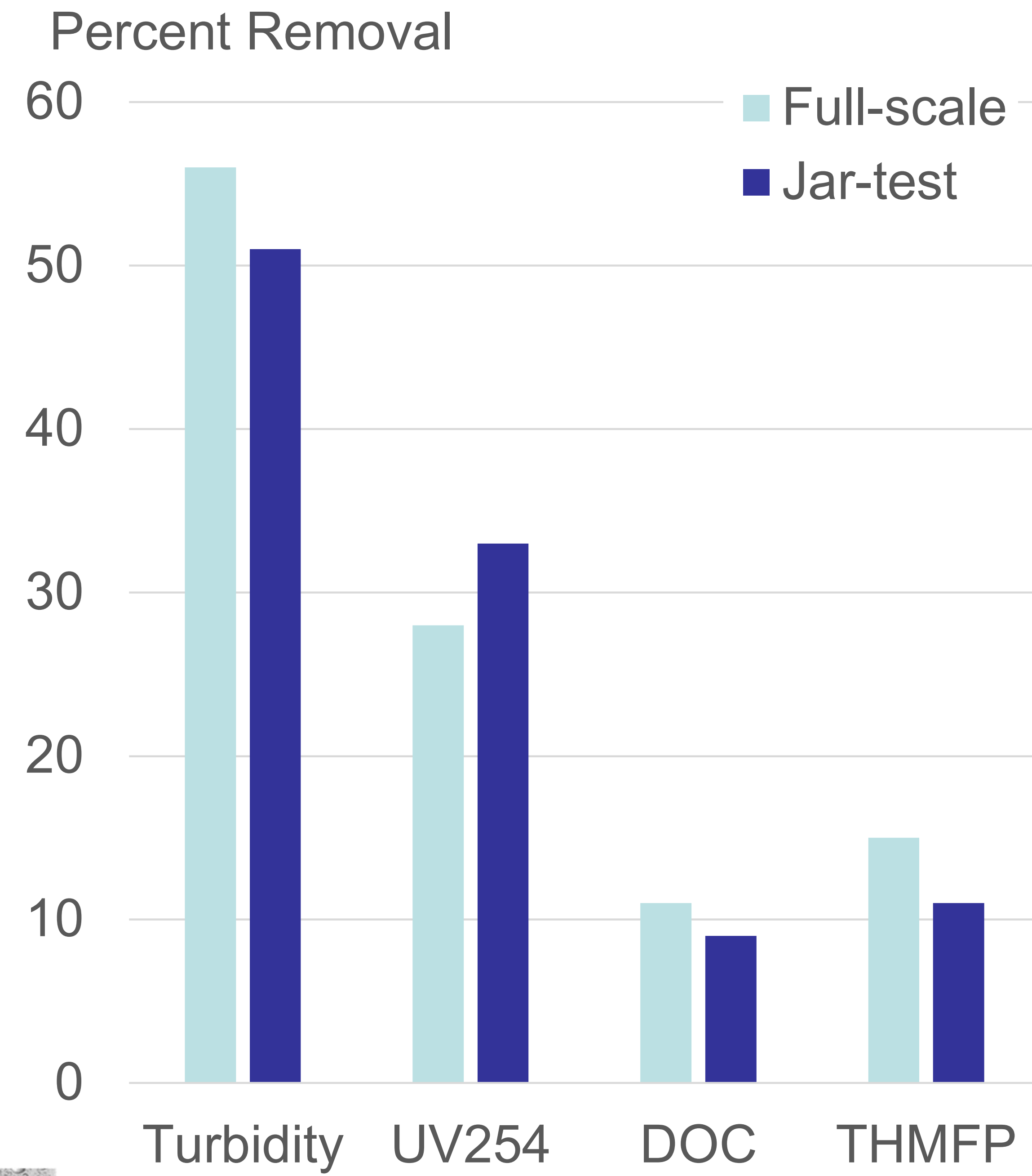
1) Removal of particles (turbidity), NOM (color/TOC/ UV_{254}), or any other water quality parameter of concern.
2) Floc size, visual appearance
3) Settling velocity
4) Filterability

★ **What you measure depends on your study goals →** ★

Need to define what question you are trying to answer!!

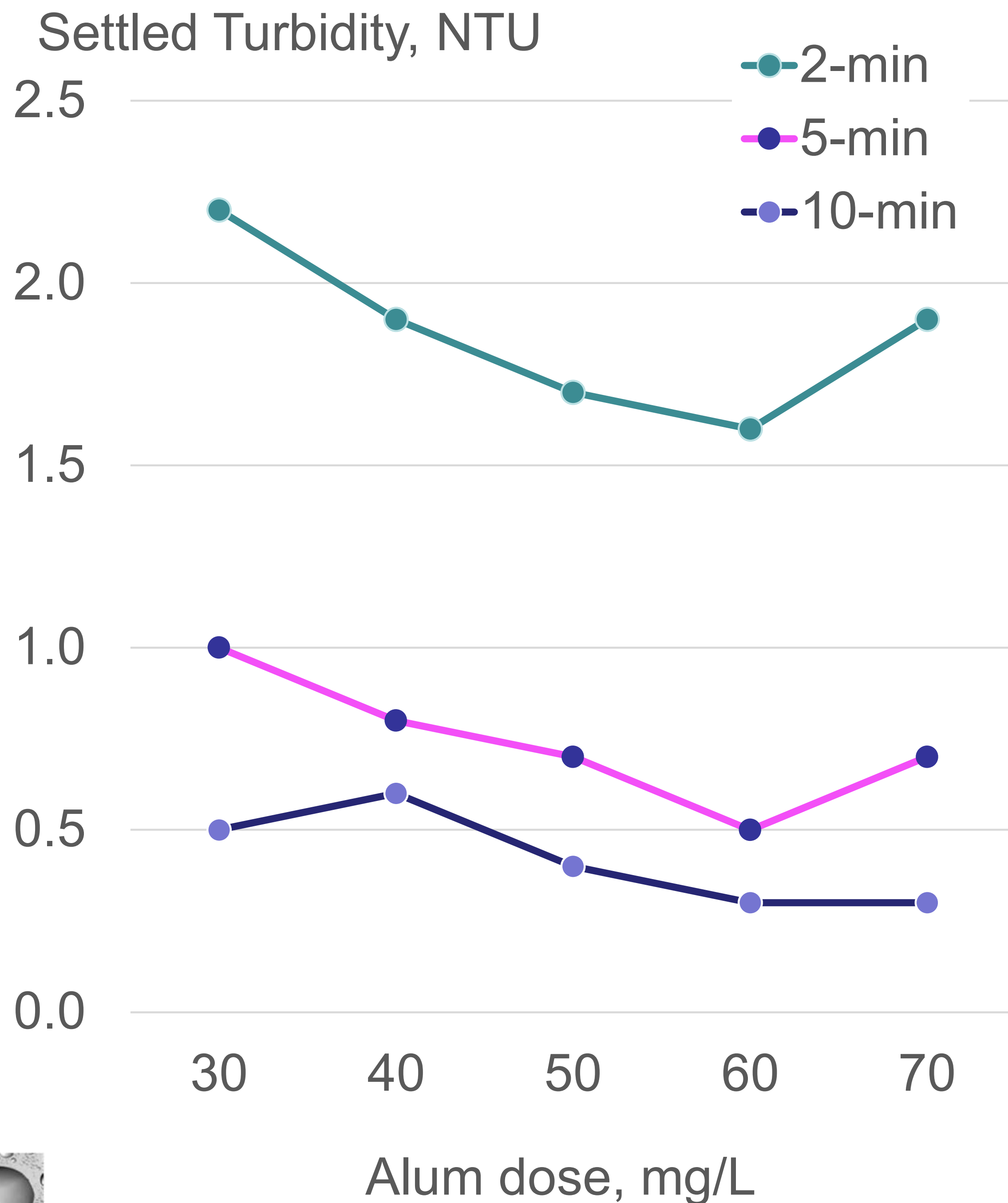
Typical Jar Test Results

Comparison with Full-scale performance



Typical Jar Test Results

Alum dose screen



JAR TESTS

<u>Before we begin</u>:

1) Need good handle of stock dosing solutions

   → how much of each chemical to add
   (WSO Water Treatment, Grade 2; AWWA Manual M37)

2) Need plant operating conditions

   → Detention times, mixing intensity (velocity gradient), loading/overflow rates

3) Need a defined procedure (AWWA Manual M37)

Water Treatment Math Practice #1
Jar tests

Q: How many µL of alum must be added to a 2L jar to achieve an alum dose of 10 mg/L?

Assume:

1) Product is 48.5% as dry alum
2) Product has a specific gravity of 1.32

Math Practice: *Coagulation*

Q: How many μL of alum must be added to a 2L jar to achieve an alum dose of 10 mg/L?

Assumptions:

1) Product is 48.5% as dry alum
2) Product has a specific gravity of 1.32

How much alum do we need?

$$\frac{10\ mg\ dry\ Alum}{1\ L} \text{x} \frac{2\ L}{1\ jar} = \frac{20\ mg\ dry\ alum}{1\ jar}$$

Tricky part: How many μL of liquid alum equals 20 mg dry alum?

→ need solution strength!

With information given, we can calculate lb (dry alum)/gal:

If liquid alum has specific gravity of 1.32, then 1 gallon of liquid alum weighs 1.32 times more than a gallon of water.

$$\frac{8.34\ lb\ \ water}{1\ gal} \text{x} \frac{1.32\ lb\ liquid\ alum}{1.0\ lb\ water} = \frac{11.0\ lb\ \ liquid\ alum}{1\ gal}$$

Math Practice: ***Coagulation***

If liquid alum weighs 11.0 lb / gal and the liquid product is 48.5% dry alum, then:

Q: How many μL of alum must be added to a 2L jar to achieve an alum dose of 10 mg/L?

$$\frac{11.0\ lb\ \cancel{liquid\ alum}}{1\ gal} \times \frac{0.485\ lb\ dry\ alum}{1\ lb\ \cancel{liquid\ alum}} = \frac{5.34\ lb\ dry\ alum}{1\ gal\ liquid\ alum}$$

Assumptions:

1) Product is 48.5% as dry alum
2) Product has a specific gravity of 1.32

$$\frac{5.34\ \cancel{lb}\ dry\ alum}{1\ \cancel{gal}\ liquid\ alum} \times \frac{1\ \cancel{gal}}{3.785\ \cancel{L}} \times \frac{1\ \cancel{L}}{1000\ mL} \times \frac{454\ \cancel{g}}{1\ \cancel{lb}} \times \frac{1000\ mg}{1\ \cancel{g}}$$

= 640 mg/mL → = 0.640 mg/μL (dry alum / liquid alum)

$$\frac{20\ \cancel{mg}\ dry\ Alum}{1\ jar} \times \frac{1\ \mu L\ (liquid)}{0.640\ \cancel{mg}\ (dry)} = \frac{31.2\ \mu L\ liquid\ alum}{1\ jar}$$

$\boxed{\text{Answer: 31.2 μL for every 10 mg/L alum}}$

JAR TESTS

1% stock solution (by weight) = **10,000** mg/L

→ Every 1 mL of 1% solution added to 2 L jar = 5 mg/L

To make 1% solution, need:

- Specific gravity and % active ingredient, or
- Solution strength: e.g. active lb/gal.

→ Convert solution strength to mg/mL

→ Divide 10,000 by solution strength in mg/mL = number of mL of chemical to add to 1L to make 1% stock

JAR TESTS

1% stock solution (by weight) = **10,000** mg/L

→ From previous example, the solution strength of bulk alum is 5.34 lb dry alum/gal or 640 mg/mL

→ Divide 10,000 by solution strength in mg/mL = number of mL of chemical to add to 1L to make 1% stock

$$\frac{10{,}000\ \cancel{mg}\ dry\ Alum}{1\ L} \text{ x } \frac{1\ \ mL\ (liquid)}{640\ \cancel{mg}\ (dry)} = \frac{15.6\ mL\ liquid\ alum}{1\ L}$$

Every 1 mL of 1% solution added to 2 L jar = 5 mg/L

Water Treatment Math Practice #2
Jar tests

Q: What is the settling velocity in cm/min corresponding to an overflow rate of 0.25 gpm/sf?

$$\frac{0.25\ \cancel{gal}}{(1\ min)(1\ \cancel{sf})} \text{ x } \frac{1\ \cancel{cu.ft.}}{7.48\ \cancel{gal}} \text{ x } \frac{12\ \cancel{in}}{1\ \cancel{ft}} \text{ x } \frac{2.54\ cm}{1\ \cancel{in}} = \frac{1.0\ cm}{1\ min}$$

Example Jar Test data sheet

Date:		Time:
		Concentration
		(mg/L)
Coagulant:		
Oxidant		
Polymer:		

Source Water				
pH	Turbidity (ntu)	Alkalinity (mg/L as $CaCO_3$)	UV254 (cm^{-1})	TOC (mg/L)

Jar Number		1	2	3	4	5	6
Rapid Mix	G (s^{-1})						
	rpm						
	Duration (s)						
Flocculation	G (s^{-1})						
	rpm						
	Duration (s)						
Coagulant Dose (mg/L)							
Volume of Coagulant Added (mg/L)							
Oxidant Dose (mg/L)							
Volume of Oxidant Added (mL)							
Polymer Dose							
Volume of Polymer Added (mL)							
Coagulation pH							

Settling Velocity (cm/min)	Depth of Sampling (cm)	Time of Settling (min)	Turbidity (ntu)	Turbidity (ntu)	Turbidity (ntu)	Turbidity (ntu)	Turbidity (ntu)	Turbidity (ntu)
TOC (mg/L)								
UV-254 (cm^{-1})								

JAR TESTS

<u>Don't try to do too much</u>!

1) Jar tests will not accurately predict residual turbidity because flocculation and settling are scale dependent. Rather, focus on <u>***trend***</u> of turbidity as a function of coagulant dose.

2) Jar tests do accurately predict DOC and UV254 removals because removal of NOM is a chemical reaction so NOM removal does not depend on separation by clarification or filtration.

3) Chemistry is independent of scale so the optimum dose and pH in a jar test will also be the optimum for the full-scale plant. (*Mixing disclaimer!*)

Zeta Meter

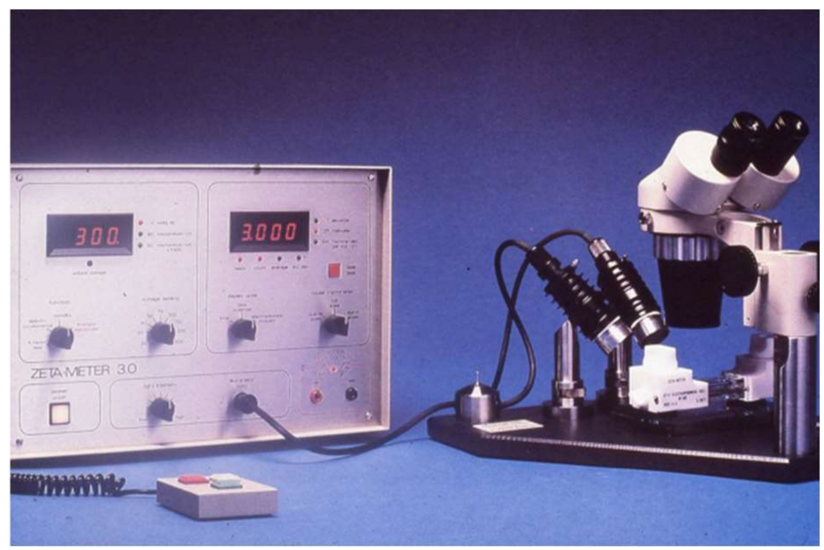
Coagulation Evaluation Tools

Zeta Meter

– Effectively measures the repulsive force between colloids → “Zeta Potential”

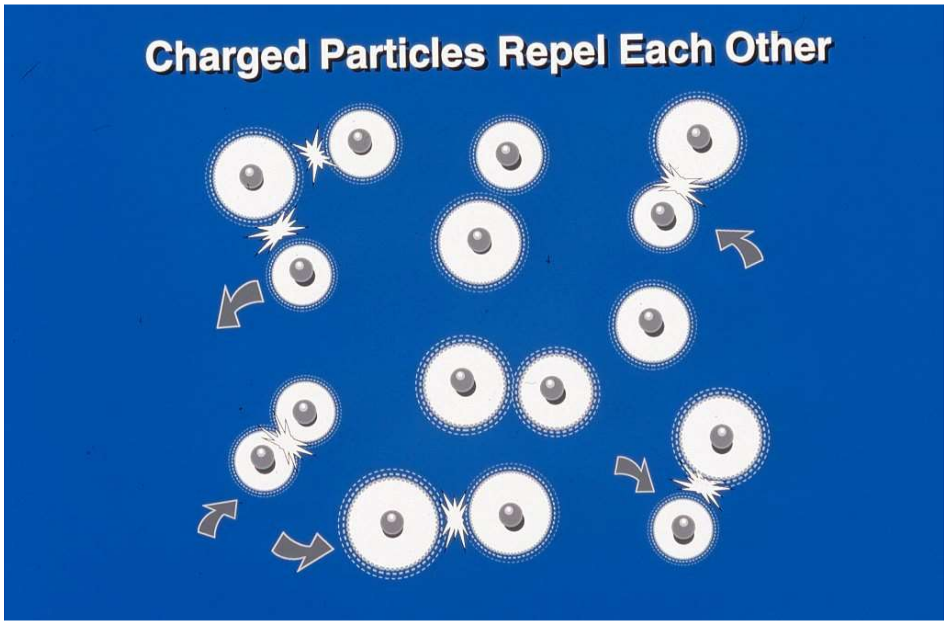
– Provides immediate results

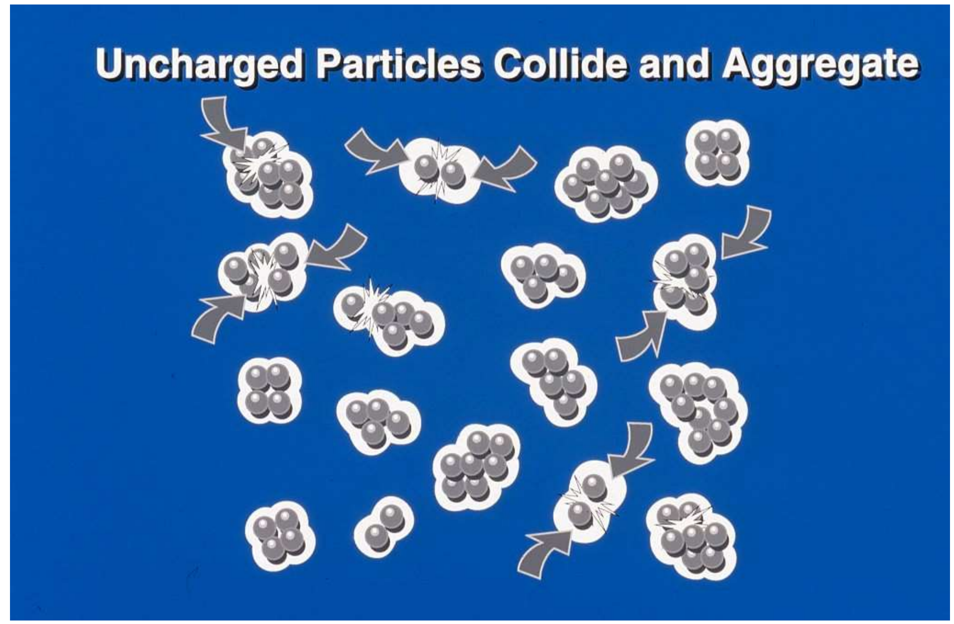
– Can be used in conjunction with Jar Tests to quickly evaluate coagulant performance



Most naturally occurring particles have a net negative surface charge

Coagulation reduces or neutralizes the particle charge so particles will aggregate

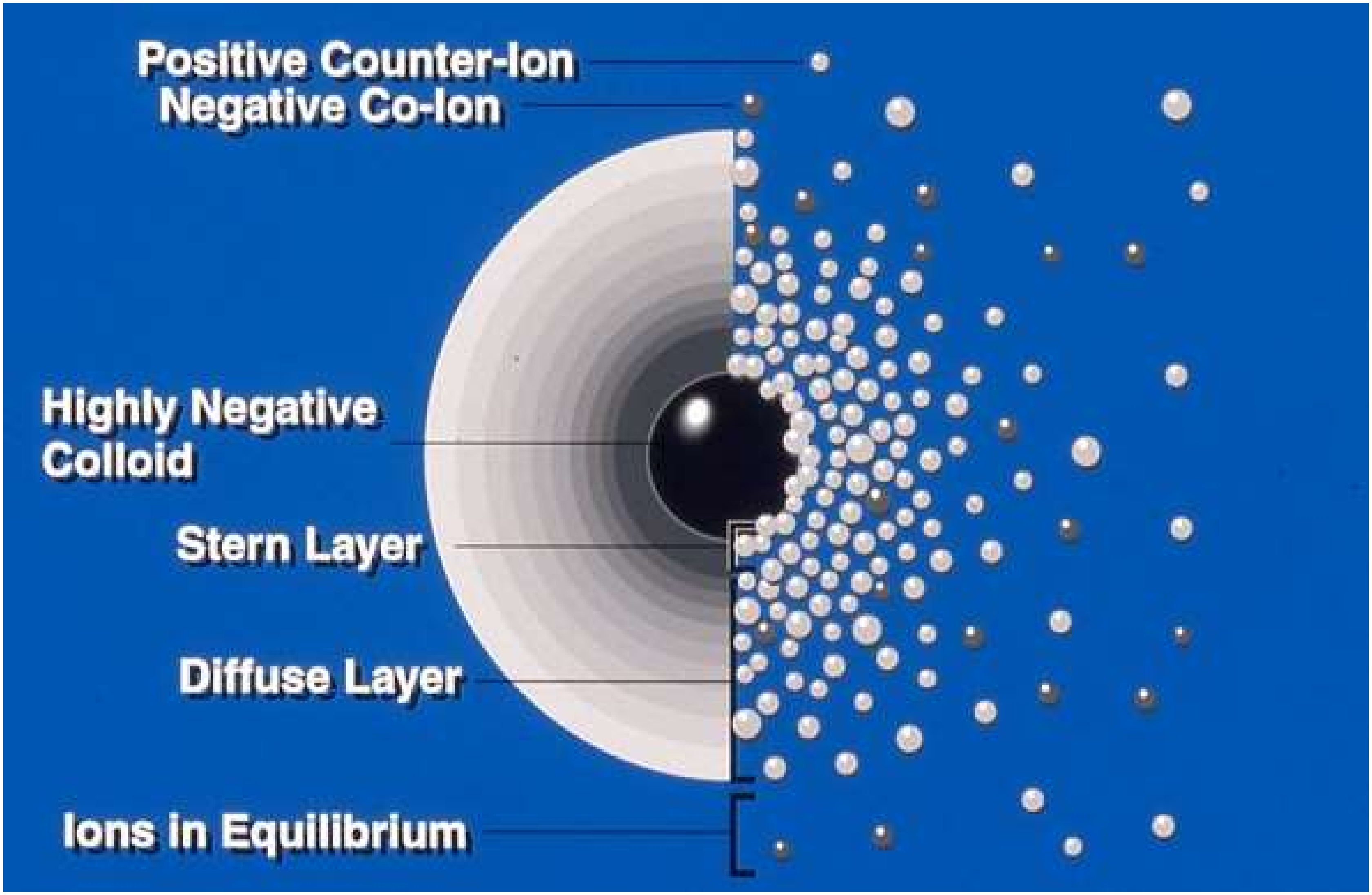




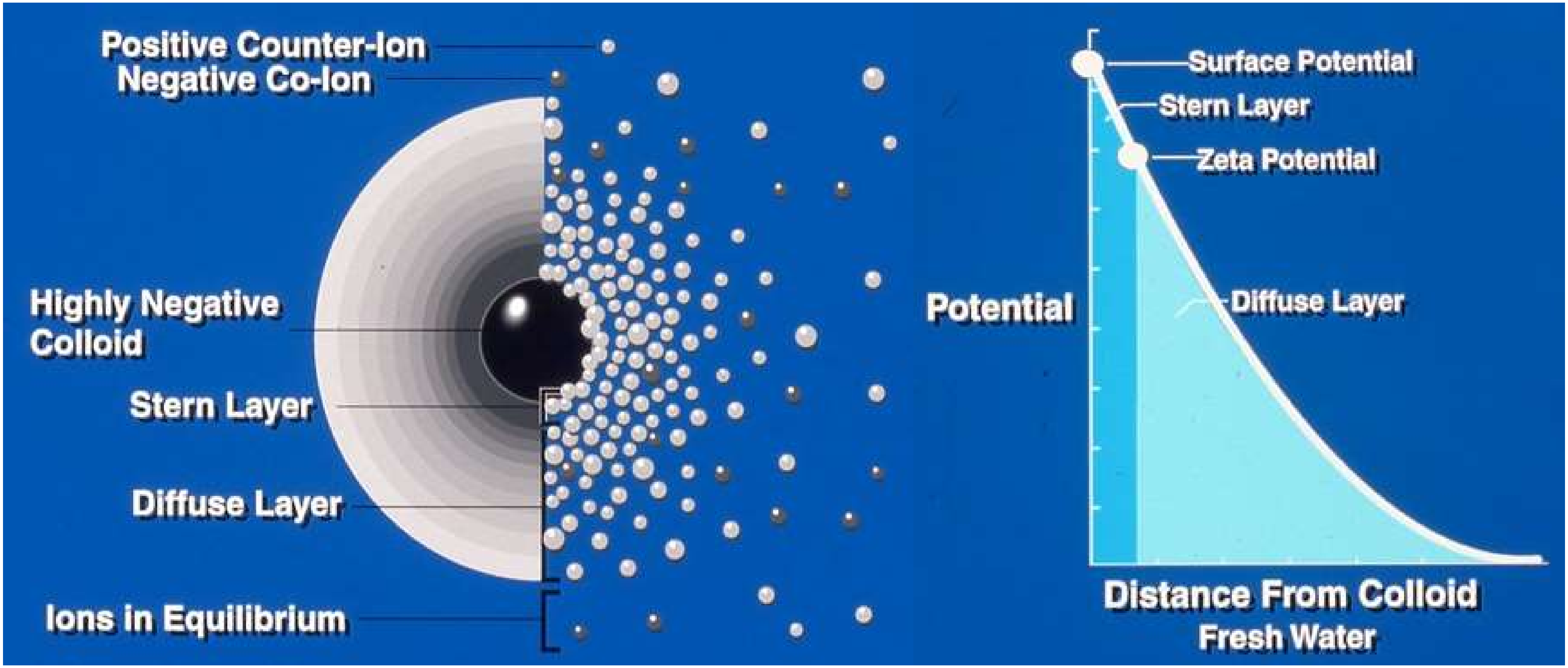
Zeta potential <u>is the natural repelling electrical force</u> between any two particles of like charge that keep them suspended.

(Water Supply Operations)

Negative Colloid with Electrostatic Field

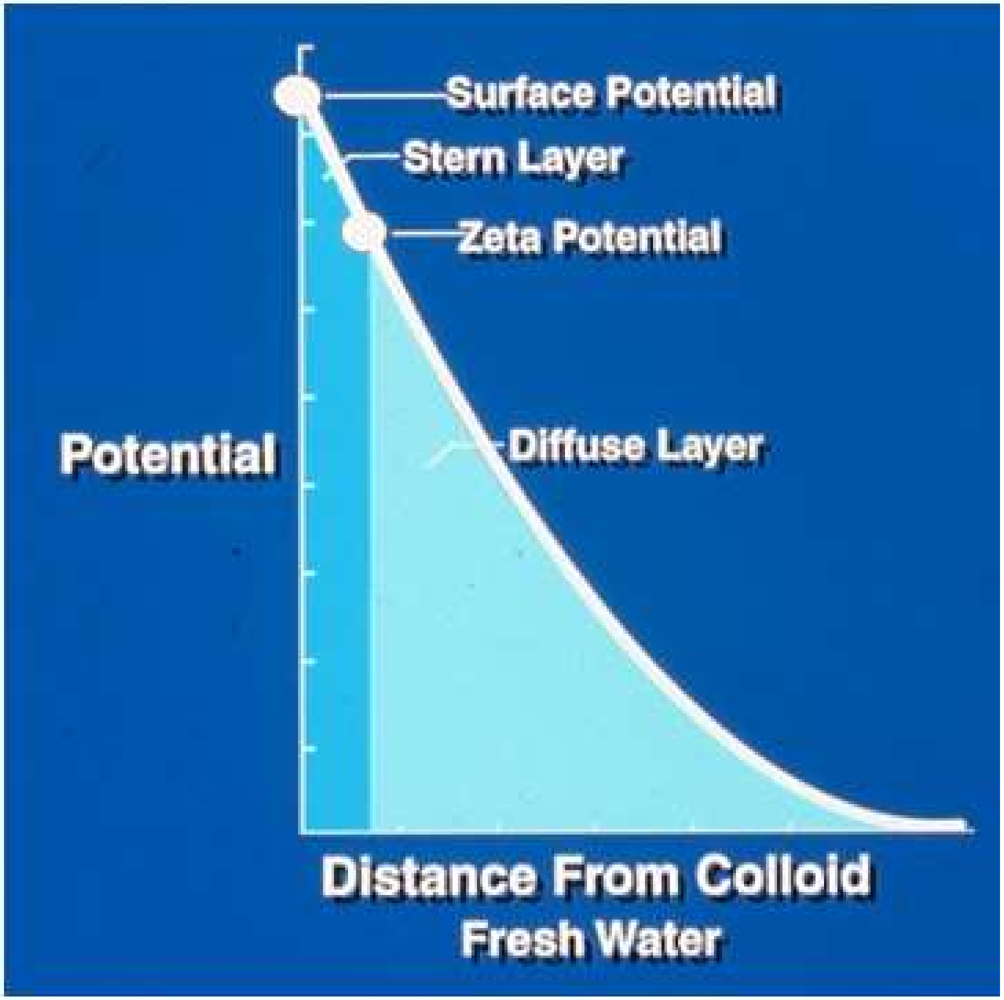


Zeta Potential



"Electrical Potential Curve" indicates strength of repulsive forces between particles and distance at which they come into play.

Zeta Potential



- Approximates the electrical potential (i.e. charge) at the particle surface.
- The greater the zeta potential, the greater the repulsive forces between particles → and therefore, more stable the suspension.
- Zeta potential can be measured fairly easily whereas the surface potential cannot.
- Changes in zeta potential indicate changes in the repulsive force between colloids.

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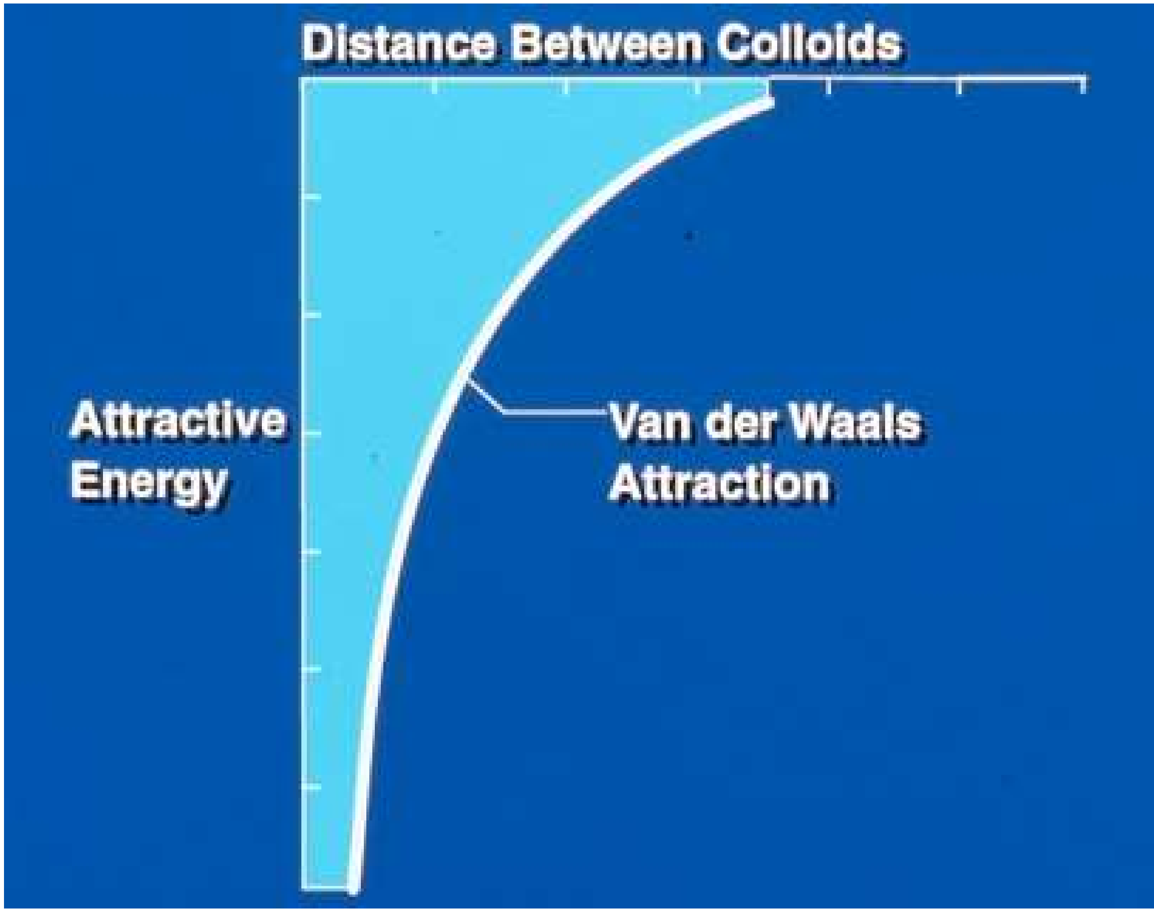
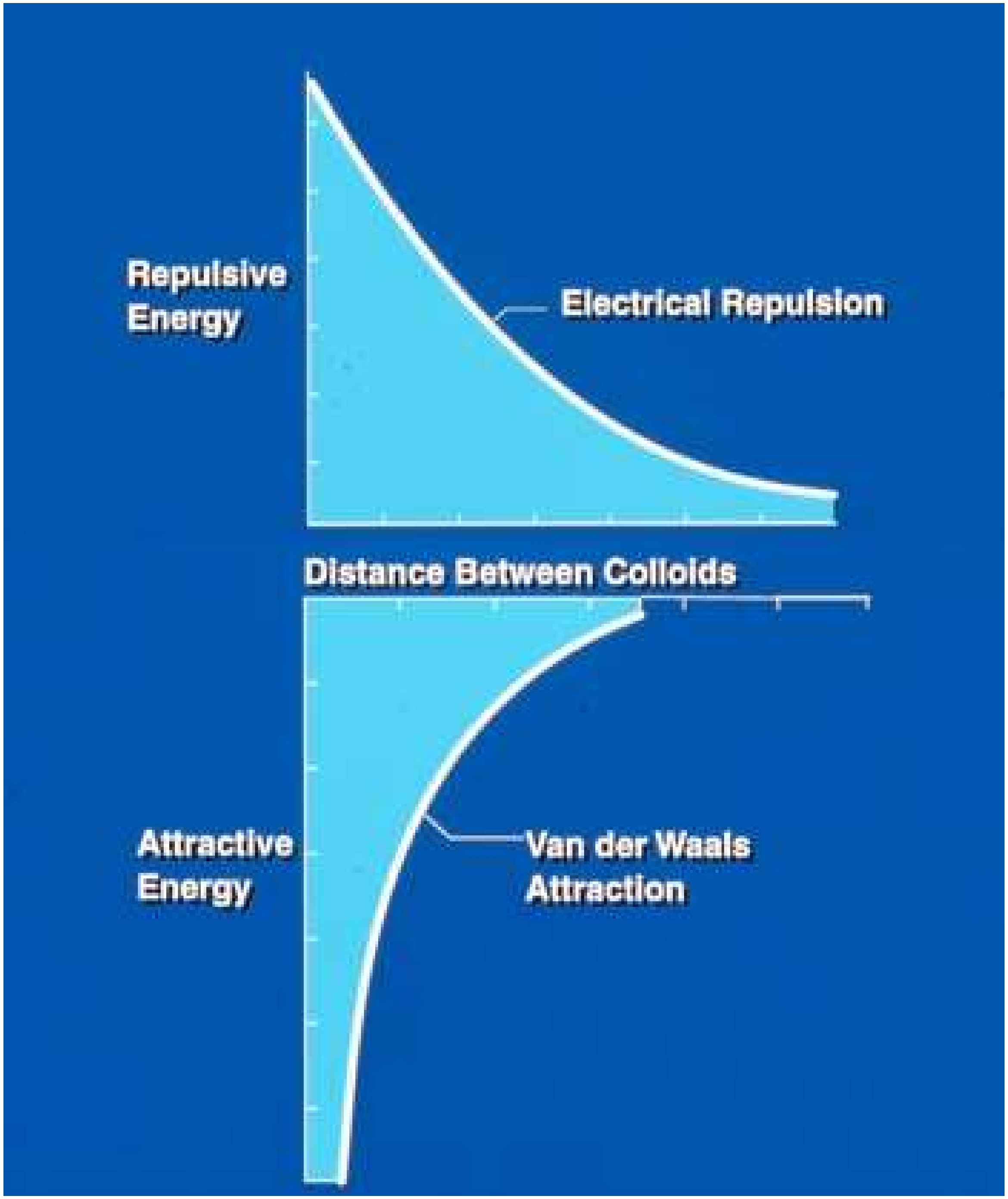
Van der Waals Attractive Force

- Result of forces between individual molecules in each colloid.
- Attractive forces are large near the particle surface, but decrease quickly at greater distances.

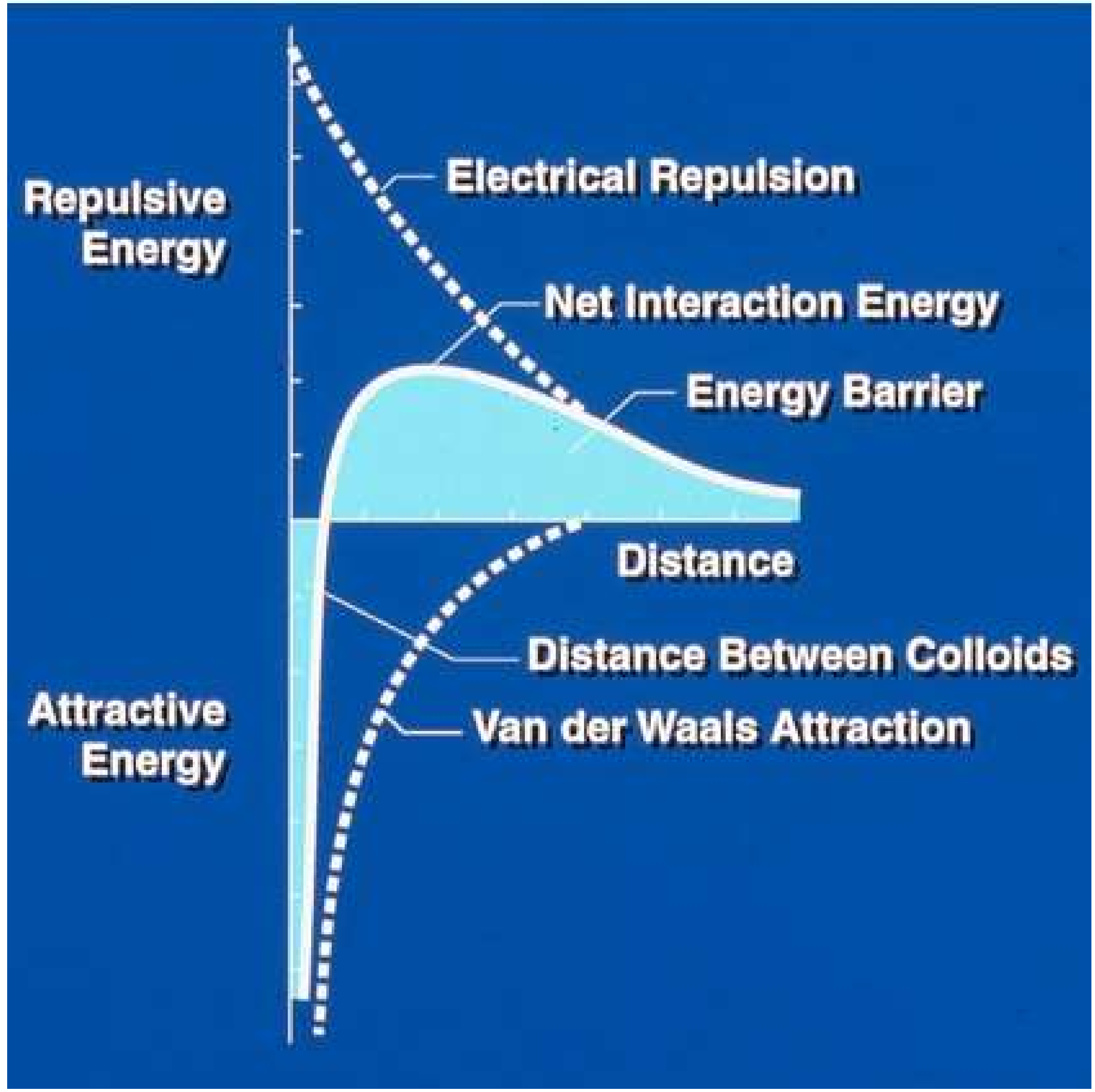


Repulsive and Attractive Forces



Net Interaction Curve

- Formed by subtracting the attraction curve from the repulsion curve



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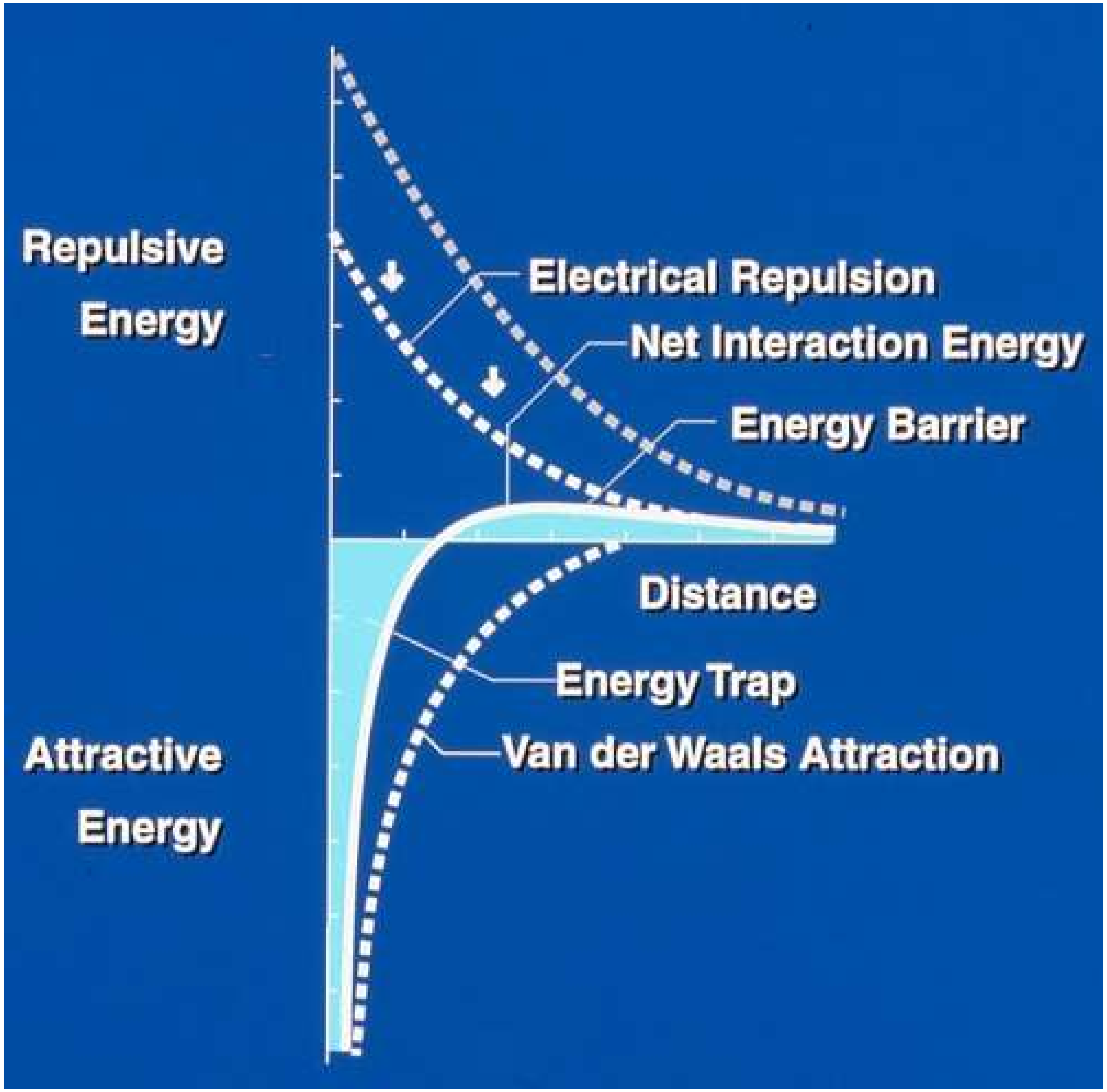
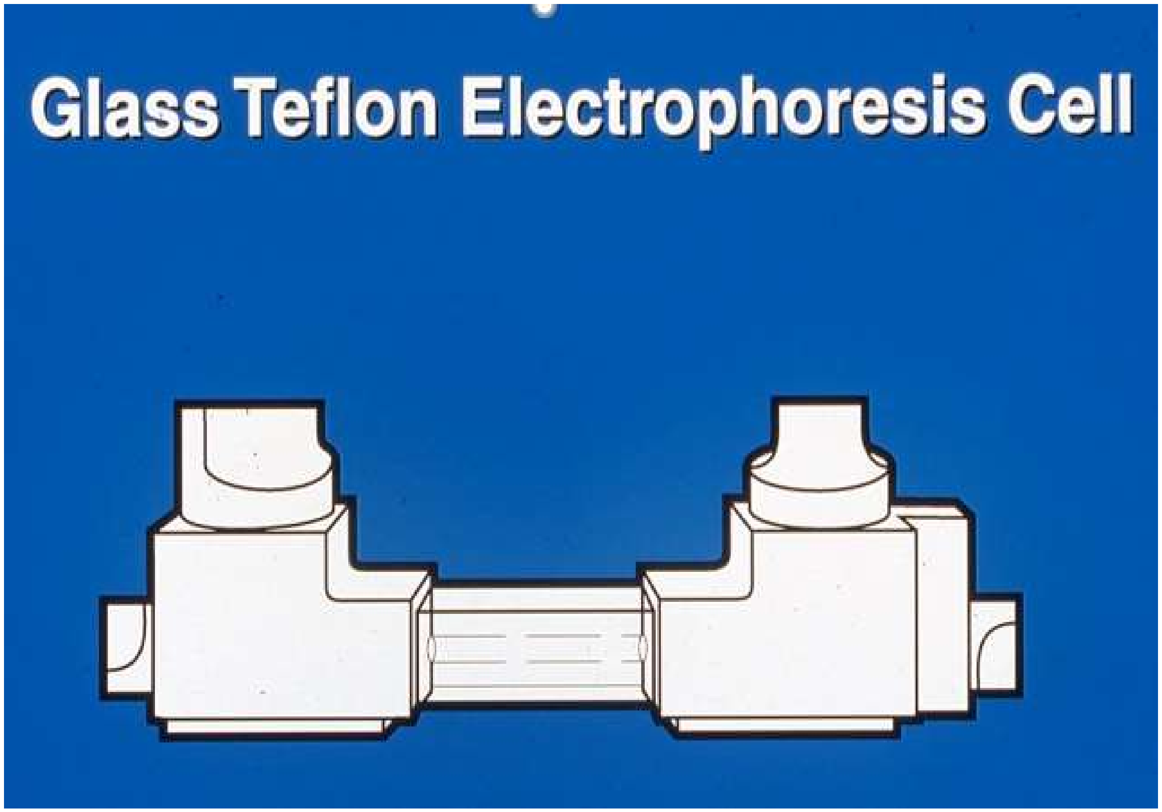
Charge Reduction

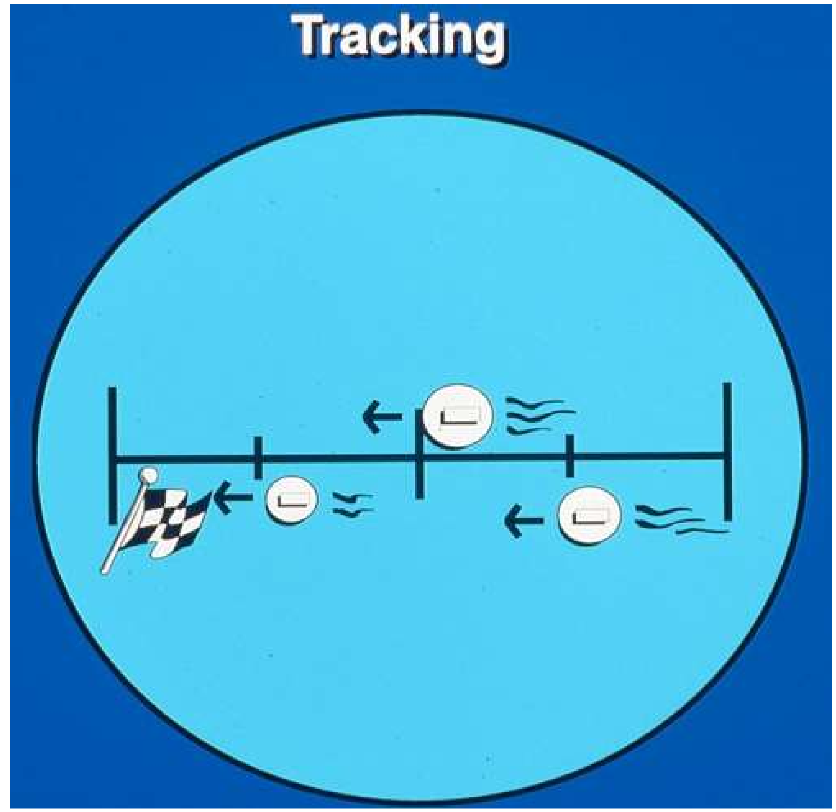
- Coagulant addition lowers the surface charge and repulsive energy curve



Zeta Meter

Zeta Meter


Glass Teflon Electrophoresis Cell


Tracking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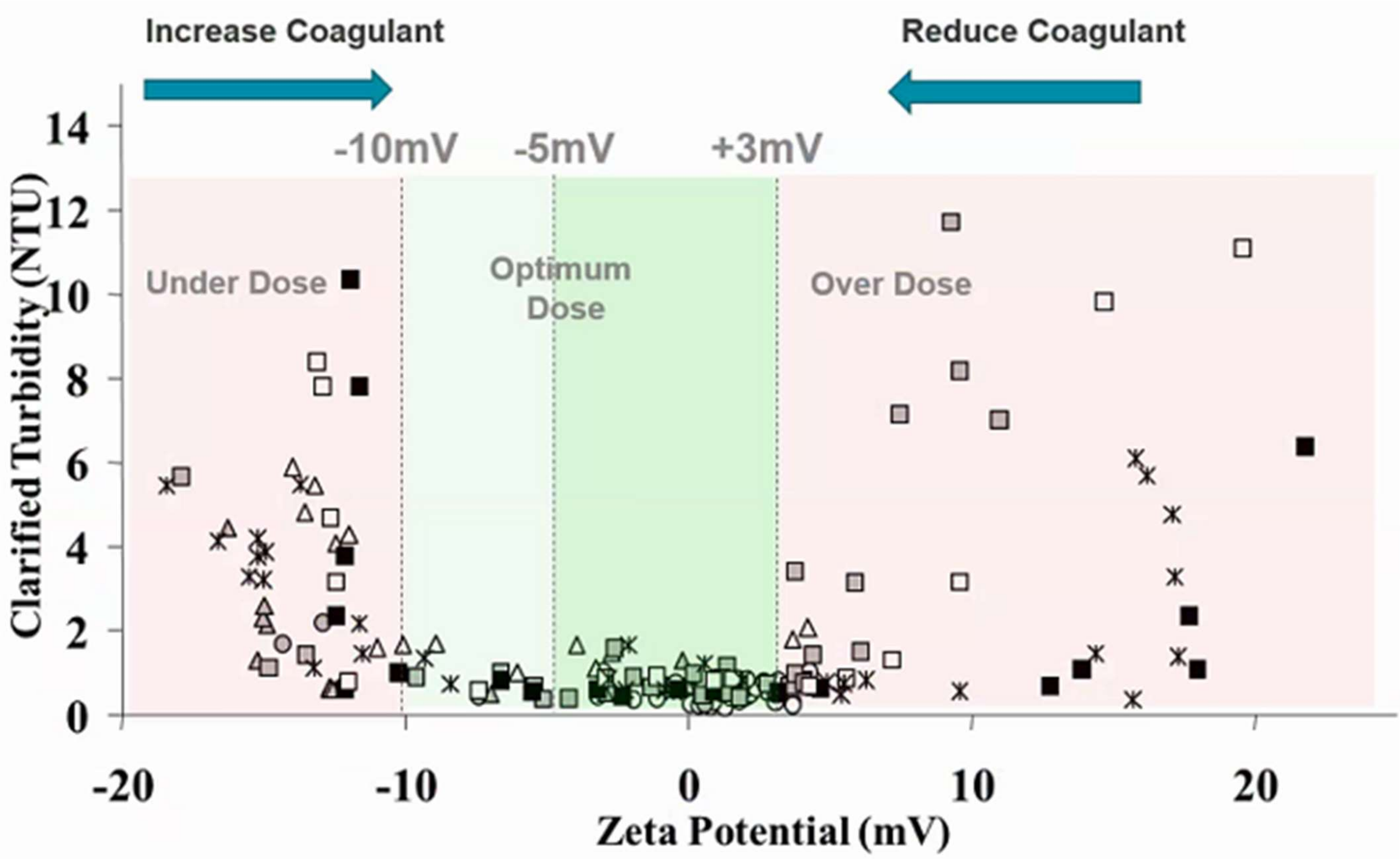
Zeta Potential – Rule of Thumb

Coagulation Level	Avg. ZP in mV
Moderate Stability	-40 to -31
Plateau of Slight Stability	-30 to -21
Threshold of Agglomeration	-20 to -11
Fair Agglomeration	-10 to -5
Excellent Coagulation	-4 to -1
Maximum Coagulation	0 to +3

Source unknown

Gregory and Carlson reported that a zeta potential between +1 and +4 was optimum for their study (2002)

Zeta Potential Operating Range



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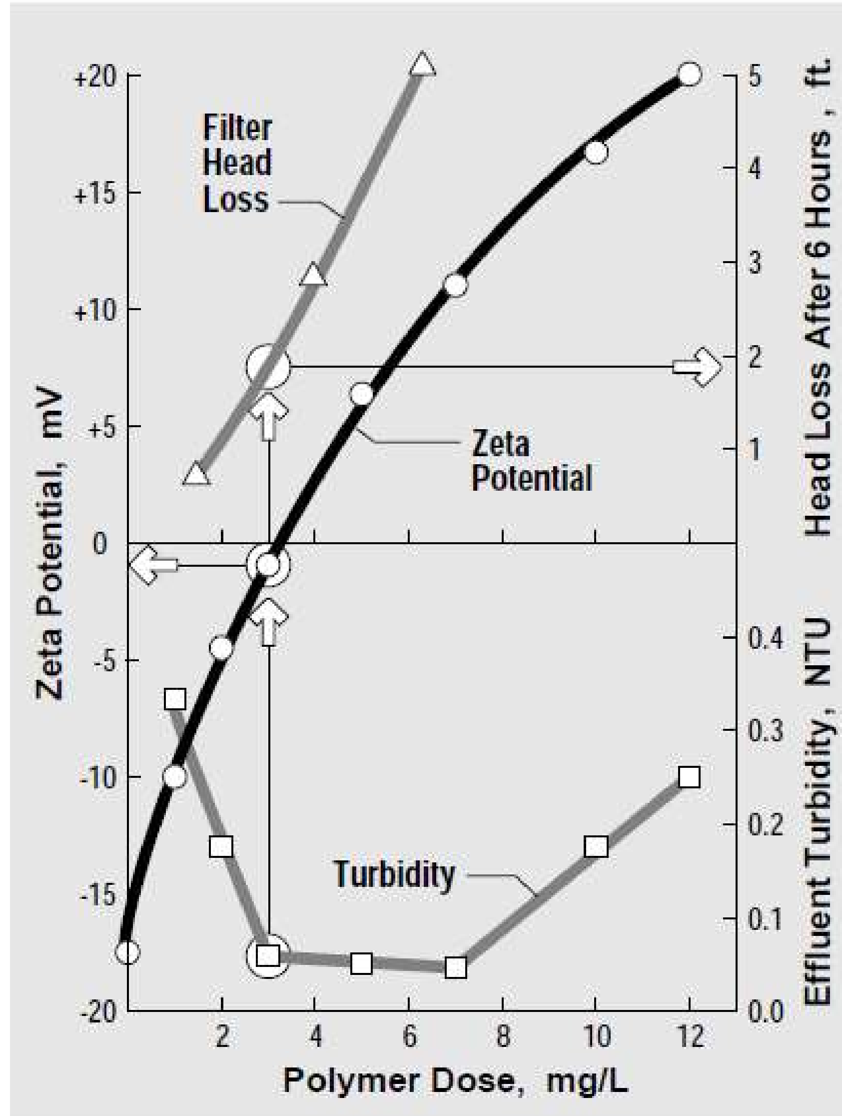
Using ZP to optimize operation

Direct filtration plant

- Increasing polymer dose from 3 to 7 mg/L lowered filtered turbidity, but increased filter headloss substantially.

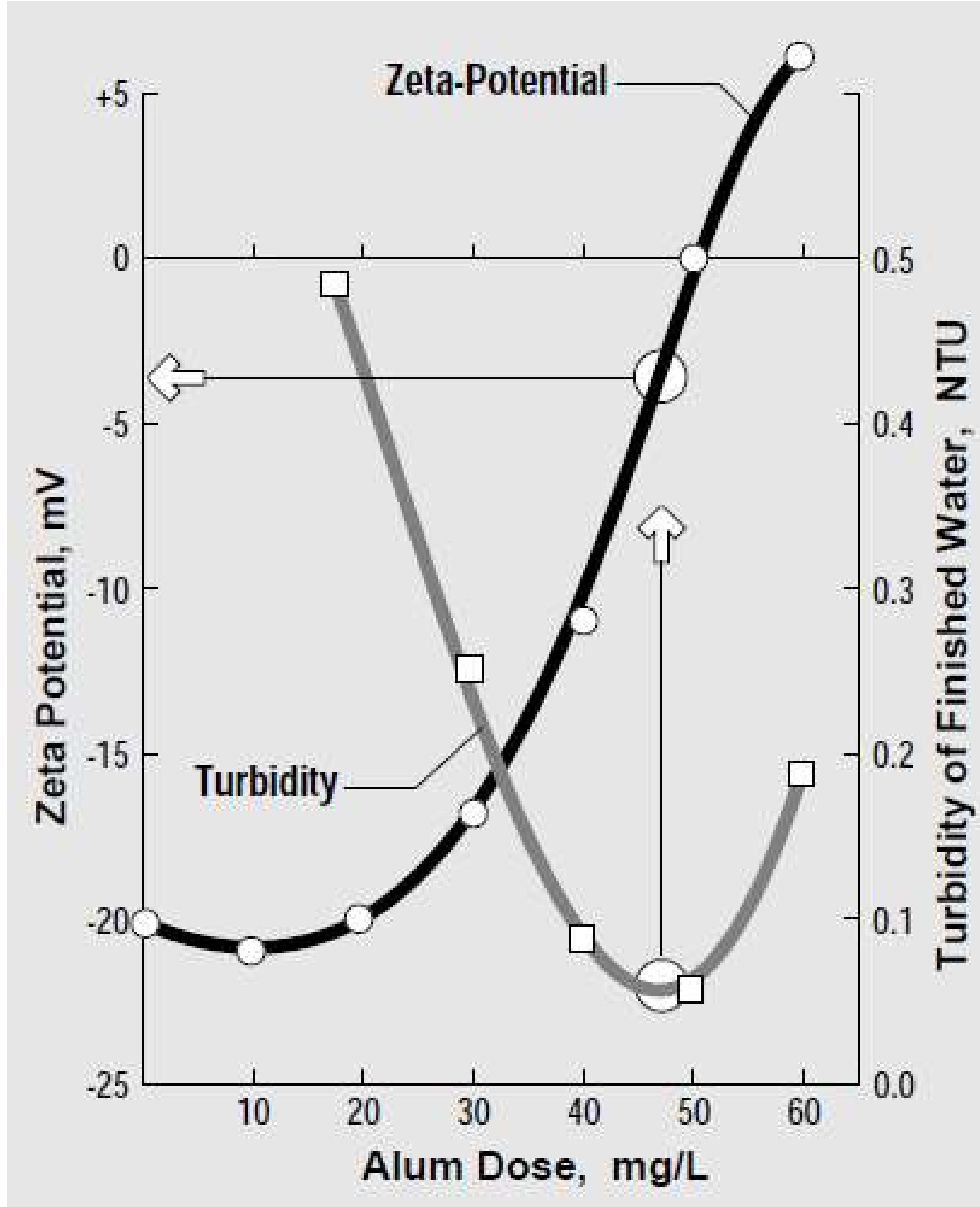
- Optimum polymer dose near ZP = 0 mV



Source: Everything you wanted to know about Coagulation & Flocculation, Zeta-Meter, Inc.

Alum dose and Zeta Potential

- Increasing alum dose resulted in more positively charged particles (increasing ZP)
- In this case, minimum finished water turbidity coincided with slightly negative ZP (~ -4mV)
- Chart also shows impact of overdosing alum



Source: Everything you wanted to know about Coagulation & Flocculation, Zeta-Meter, Inc.

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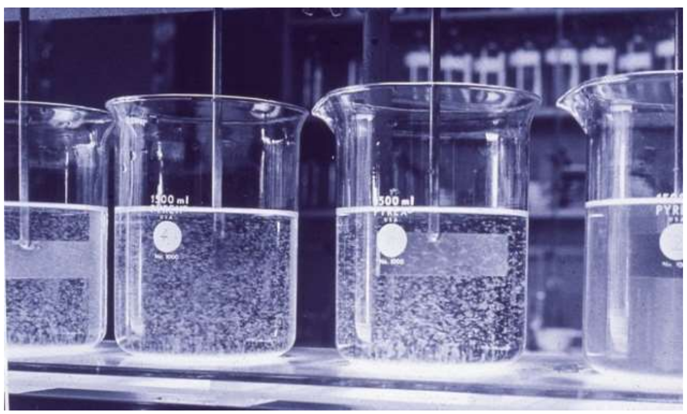
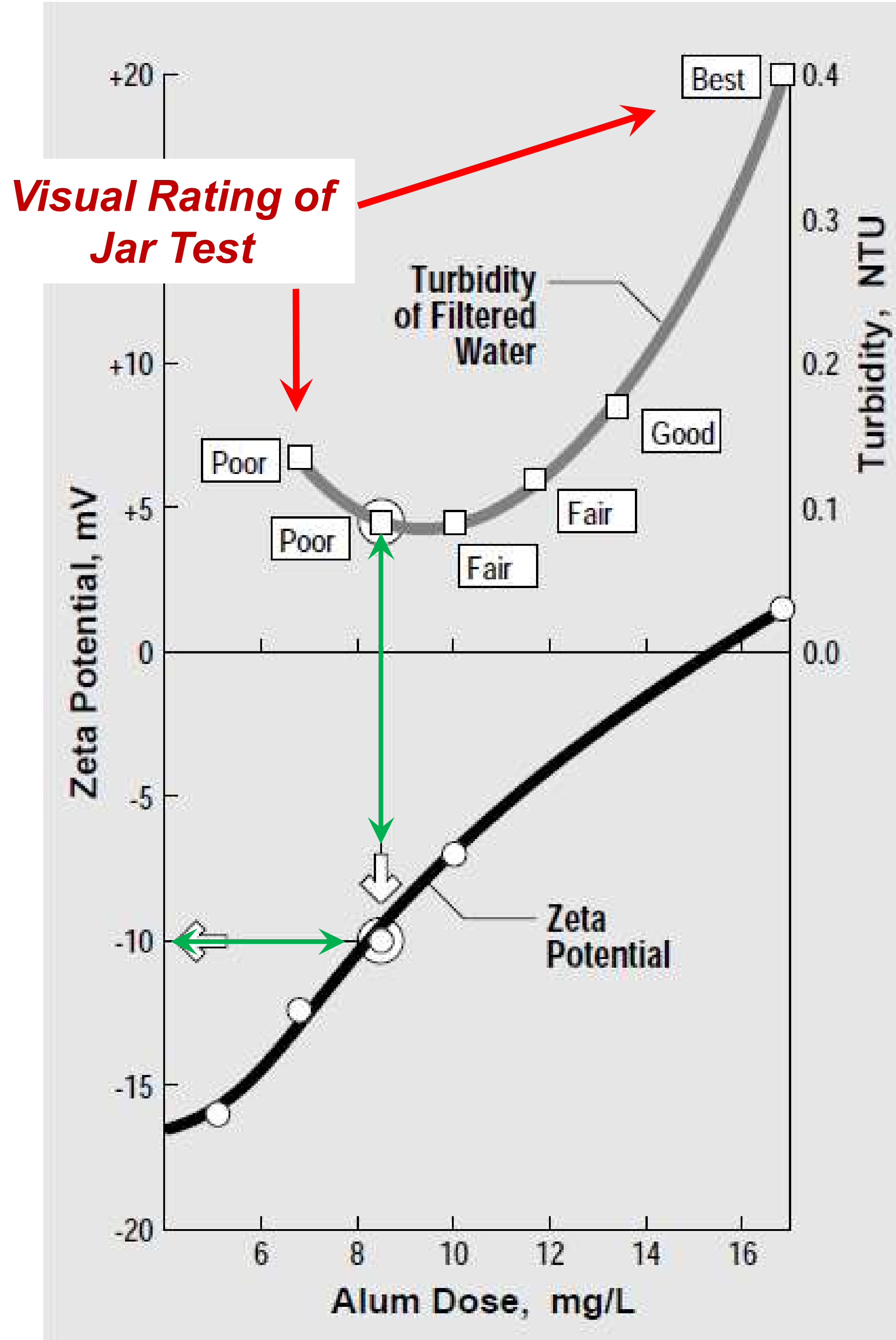
Limitations of Visual Evaluation

- Be careful not to rely solely on visual observations
- In this case, optimum alum dose coincided with ZP < 0 mV





Source: Everything you wanted to know about Coagulation & Flocculation, Zeta-Meter, Inc.

Coagulation Evaluation Tools

Zeta Potential

- Do not need to measure zeta potential everyday unless source water quality changing quickly.
  - Measure more frequently when evaluating coagulants or changing doses
- Some degree of variability → Collect enough data to identify trends and outliers.
- Do not make coagulant dose changes based on one data point; look for confirmation and trends.

HM Zeta: coagulant and dose change

HM ZETA METER TEST RESULTS

DATE	Time	Counts	NEW ZETASIZER	DEV.	ALUM DOSAGE	Sample from Train	CLW NTU	RW UV	CLW1 UV	Initials	Comments
03/27/23	7:45	4	4.786	0.2086	55	1	0.082	0.145	0.044	WR	
03/28/23	5:01	5	3.906	0.5301	55	1	0.089	0.145	0.046	KD	
04/01/23	3:50	4	5.27	0.5591	55	1	0.082	0.145	0.044	CNS	
04/01/23	23:04	5	2.923	0.384	55	1	0.087	0.16	0.042	CAJ	
04/08/23	4:10	4	4.437	0.5452	55	1	0.084	0.118	0.036	BTS	
04/09/23	3:50	5	5.381	0.5505	55	1	0.098	0.113	0.020	CNS	
04/10/23	10:50	3	13.16	0.1337	55	1	0.104	0.138	0.044	MK	start acid alum
04/10/23	14:50	3	8.58	0.7752	50	1	0.141	0.138	0.044	MK	
04/10/23	19:35	5	7.726	1.123	45	1	0.365	0.138	0.044	CNS	
04/10/23	19:35	3	7.716	0.7352	45	1	0.365	0.138	0.044	CNS	
04/11/23	9:25	5	5.894	0.5934	45	1	0.098	0.134	0.041	KD	
04/12/23	3:40	5	5.982	0.4314	45	1	0.112	0.117	0.042	BTS	
04/15/23	3:50	5	3.99	0.3749	45	1	0.088	0.13	0.042	CNS	
04/16/23	1:28	4	6.872	0.4787	45	1	0.08	0.102	0.031	TV	
04/16/23	1:28	5	7.53	0.7612	45	1	0.08	0.102	0.031	TV	
04/19/23	15:35	4	1.874	0.4385	45	1	0.095	0.136	0.043	DR /MK	
04/22/23	1:41	4	1.217	0.486	45	1	0.081	0.122	0.044	CJ	
04/23/23	3:50	5	4.312	0.4503	45	1	0.073	0.131	0.042	CNS	
04/29/23	4:15	3	4.298	0.476	45	1	0.076	0.134	0.043	CNS	
04/29/23	23:30	4	4.607	0.4218	45	1	0.071	0.119	0.045	BTS	
05/01/23	10:56	3	2.786	0.4911	45	1	0.068	0.143	0.041	KD	
05/02/23	14:45	5	3.422	0.2775	45	1	0.088	0.128	0.046	MEA	
05/05/23	20:34	4	1.837	0.579	45	1	0.117	0.153	0.046	PO	
05/07/23	3:05	5	3.107	0.2066	45	1	0.083	0.154	0.043	DR	
05/09/23	8:11	5	2.777	0.2831	45	1	0.088	0.05	0.047	TV	
05/12/23	2:13	5	0.09509	0.373	45	1	0.107	0.167	0.043	DR/WR	
05/13/23	20:23	4	-1.089	0.3812	45	1	0.143	0.165	0.049	PO	
05/14/23	21:42	5	-0.9546	0.2926	55	1	0.139	0.167	0.05	KD	Stop A7, restart Alum
05/15/23	2:07	5	0.9873	0.4849	60	1	0.123	0.175	0.053	PO	
05/15/23	10:16	4	-0.6772	0.3815	60	1	0.109	0.175	0.053	CJ	
05/16/23	17:47	4	1.227	0.5612	60	1	0.282	0.171	0.049	CNS	
05/20/23	2:32	4	0.9751	0.577	60	1	0.208	0.186	0.052	KD	
05/21/23	20:50	5	-1.759	0.1844	60	1	0.611	0.195	0.045	DR	
05/22/23	9:30	4	1.241	0.0259	65	1	0.222	0.183	0.056	CNS	
05/23/23	8:30	4	3.319	0.4303	65	1	0.134	0.201	0.052	BTS	
05/26/23	2:55	5	2.601	0.5388	65	1	0.114	0.191	0.05	WR	

Test Prep:

Q: In coagulation, once the zeta potential forces are reduced below the ____________, the particles in suspension will start to coalesce.

a. Molecular forces

b. Van der Waals forces

c. Ionic forces

d. Covalent

Answer: b. Van der Waals forces

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Coagulation Evaluation Tools

<u>Streaming Current Monitor</u>

– Useful as an in-line "*Pseudo*-Zeta Potential"

– Provides immediate results

– Only an indicator of *Net Ionic Charge* – output is nondimensional (i.e. no units)

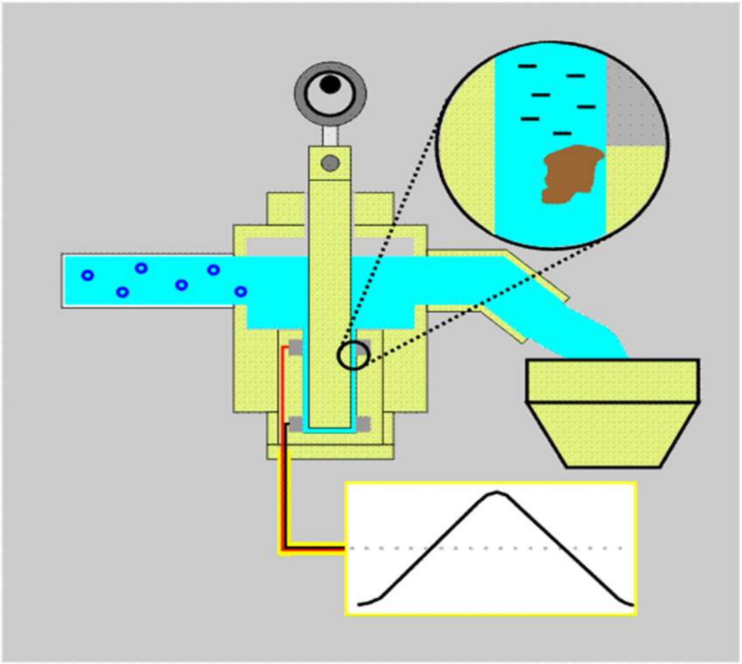
– Can be calibrated with a Zeta Meter and used in conjunction with Jar Test to quickly control coagulant performance

Streaming Current Monitors

How do they work?

- Most have a reciprocating piston that causes the water sample to flow up and down in the space between the piston and cylinder.

- Tight clearance (0.010”) forces the water to move rapidly across the surfaces of the electrodes.

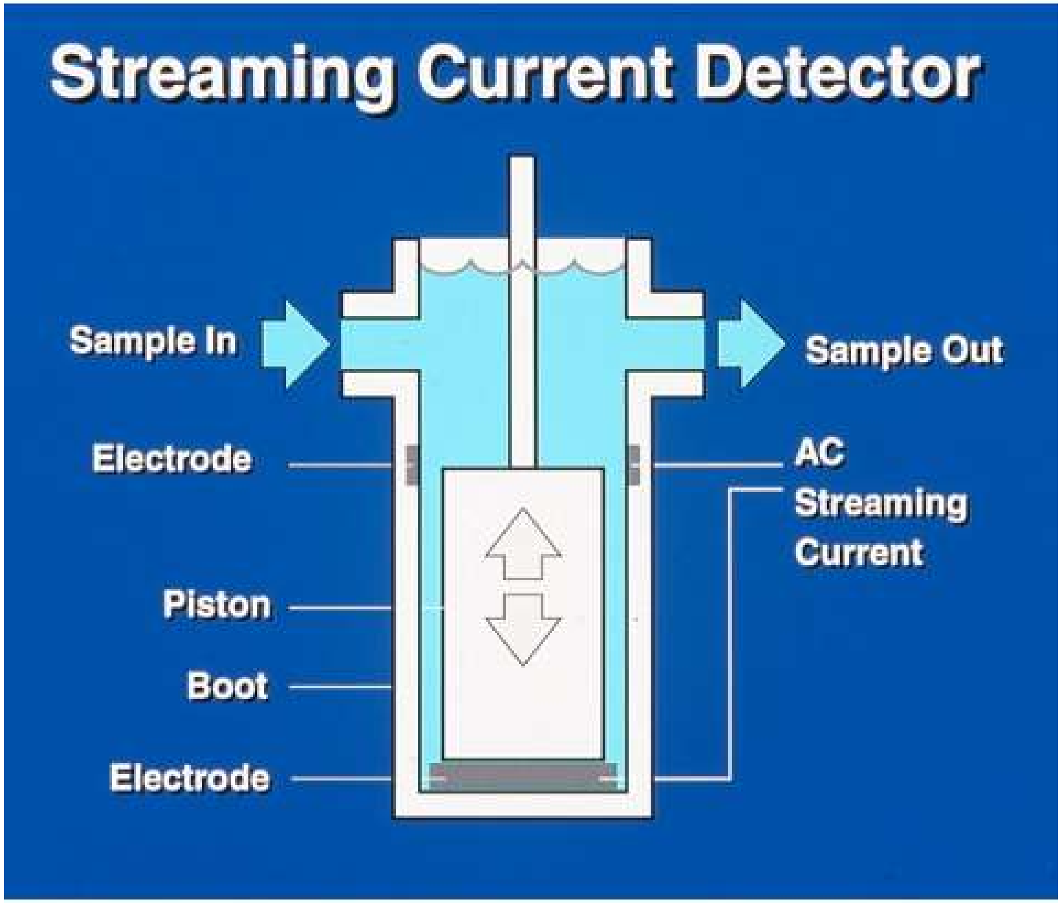


- AC current produced by the reciprocating action is detected by the electrodes and amplified and conditioned to produce the streaming current signal.

Streaming Current Monitors

How do they work?

- Water flowing through a tube induces an electric current and voltage difference between the ends of the tube.
- Charged particles in the water loosely adhere to the tube wall and affect the zeta potential of the wall.



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Streaming Current Monitors

Key Point:

- Streaming current is affected by, but <u>not</u> a direct measurement of particle charge.
- Therefore, SCMs provide only a relative indication of particle charge.

❖ Changes in streaming current are relevant although the actual value is not.

Streaming Current Monitors

Whereas, we use Zeta Potential to help *find* optimum coagulation conditions, Streaming Current is used to ***maintain*** it.

- → First find/define optimum coagulation and then set SCM reading to a value of zero (baseline).
- → Subsequent variations in streaming current can be used to adjust chemical dosing.
  - » Trending positive = over dosing
  - » Trending negative = under dosing

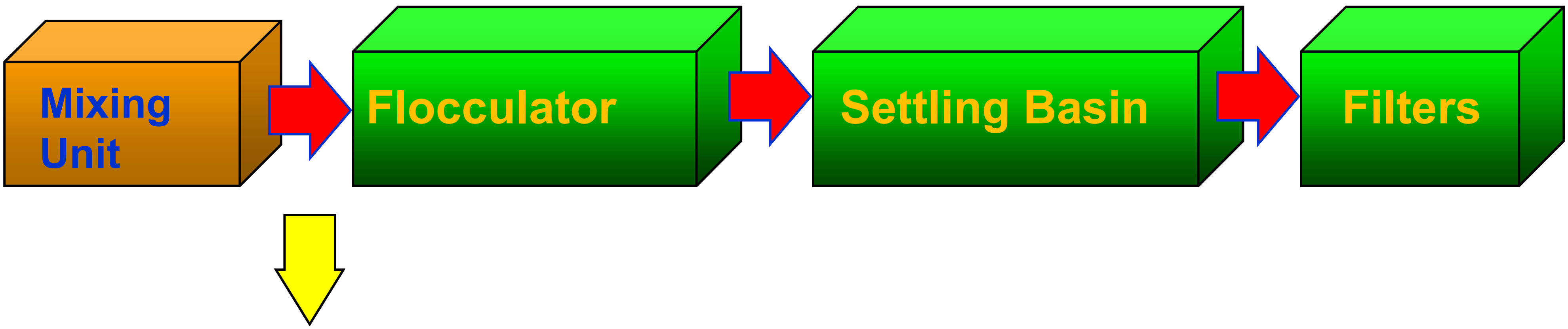
Streaming Current Monitors

Impact of pH:

- Any change in pH will affect streaming current reading even if the coagulant dose has not been changed.

Recall: pH affects surface charge of particles and functional groups on NOM.

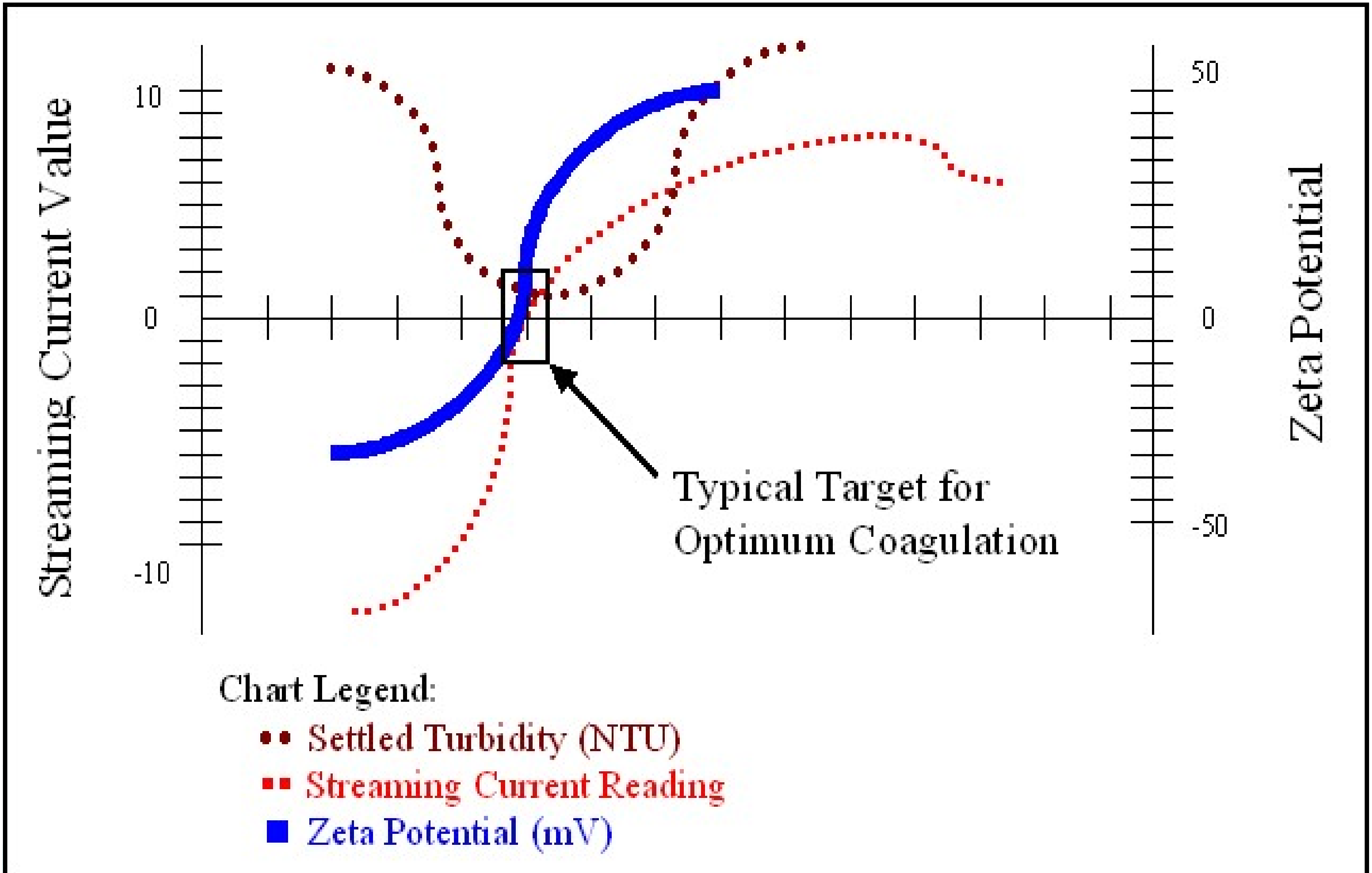
Sensor Location



Sample right after thorough mixing has been achieved.

❖ Key advantage: allow continuous monitoring and automated feedback control of coagulant dosing.

Streaming Current is related to Zeta potential but is not the same value



Test Prep:

Q: What type of instrument will help operators improve the coagulation process the most?

a. Turbidimeters at raw water, sedimentation, filters
b. Accurate venturi or magnetic flow meters
c. Streaming current monitors
d. Particle counters

Answer: c. Streaming current monitors

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Test Prep:

Q: What does a streaming current detector measure on a continuous basis?

a. The negative and positive charges
b. The net positive charge
c. The colloidal surface charge
d. The net ionic charge

Answer: d. The net ionic charge

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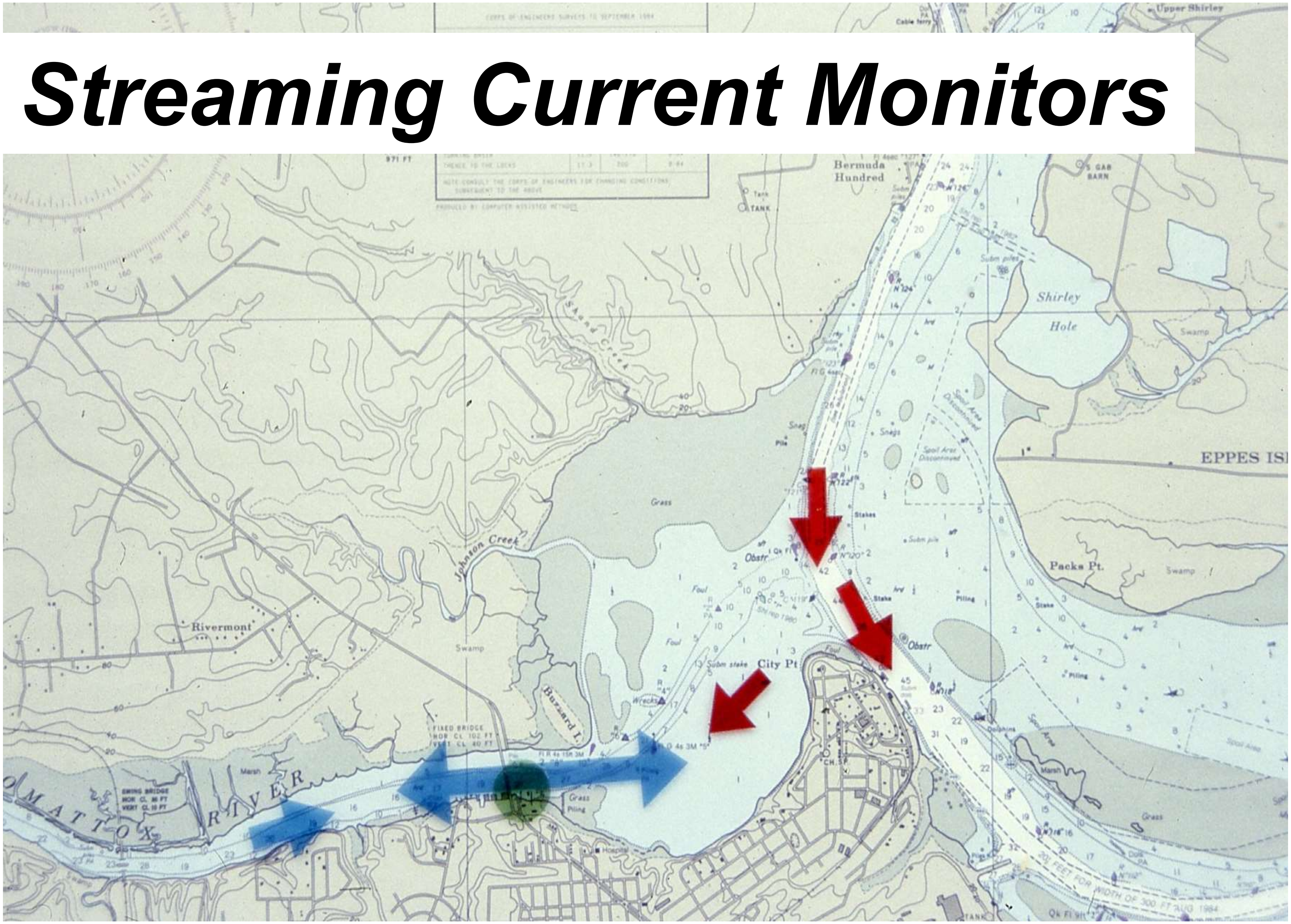
Streaming Current Monitors



Water Quality Challenge: Confluence of Two Rivers – Different WQ Characteristics

Intake Location – WQ Influence

SCM and Automated Control

Before:

- Coagulant feed pump flow paced, but
- Manual adjustments to coagulant dose required frequently due to changing source water quality.

After:

- Automatic Control: takes SCM signal and sets dosage based on charge demand; Coagulant feed based on charge demand AND flow variation.

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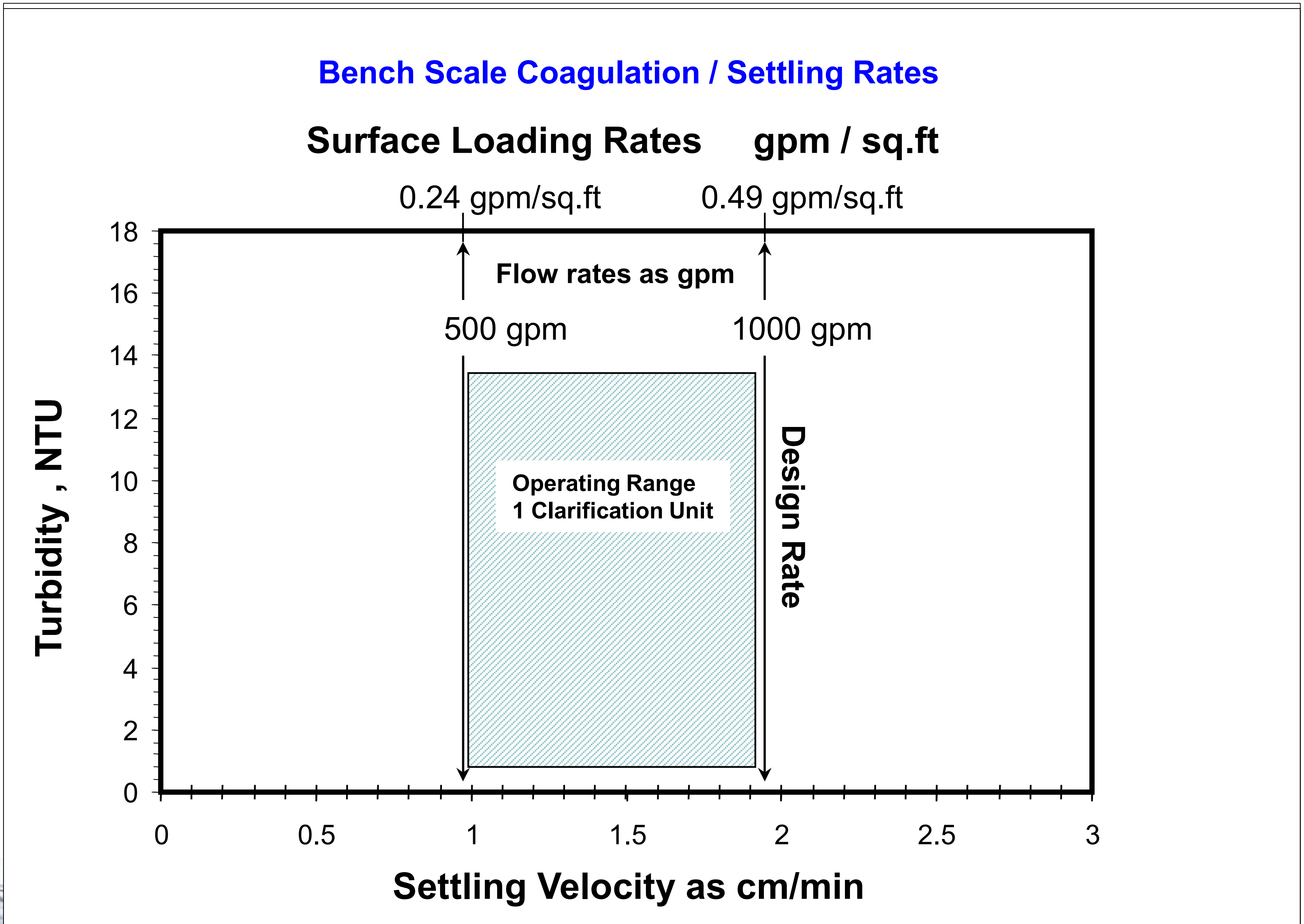
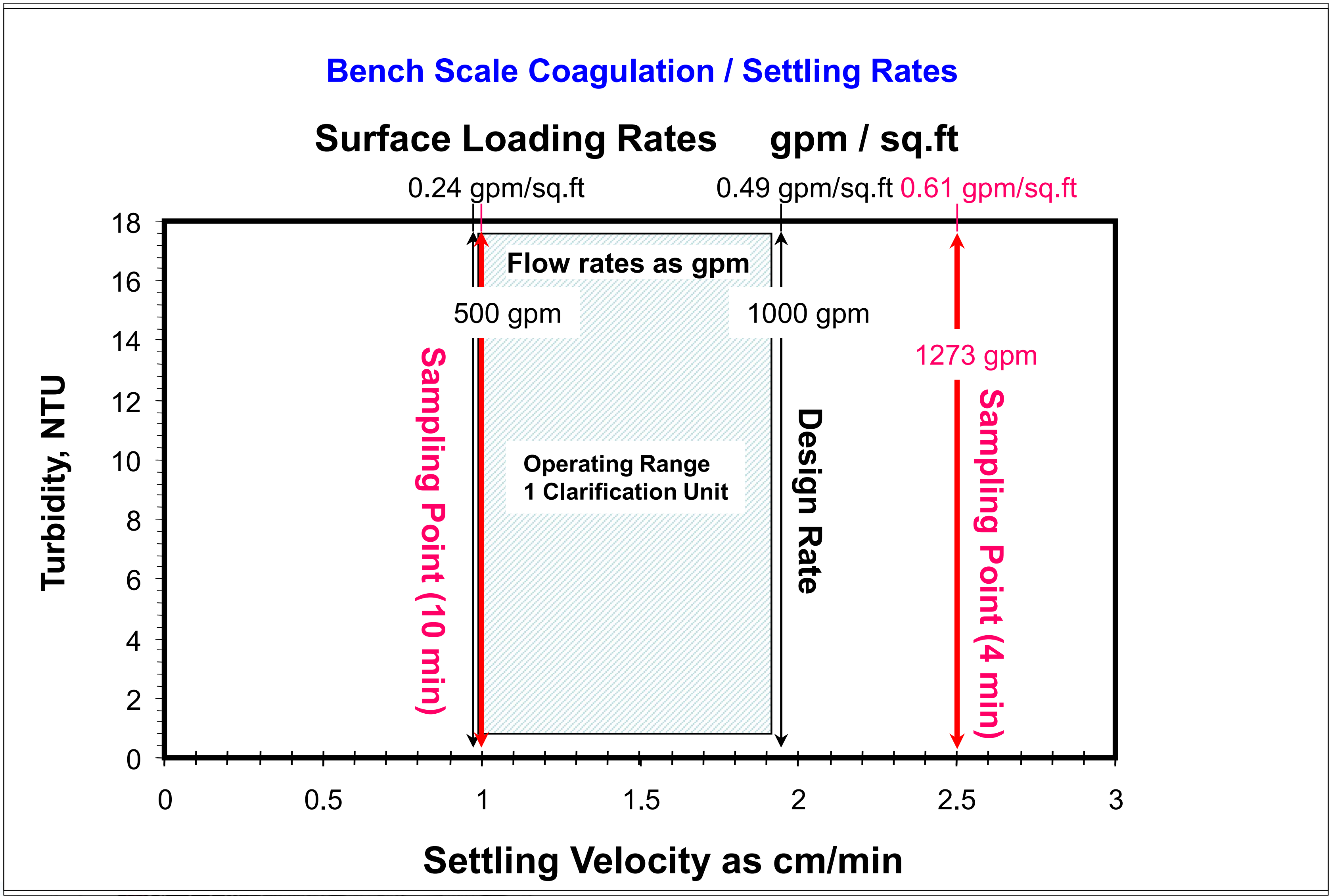
Newport News Waterworks

GOOD LUCK!

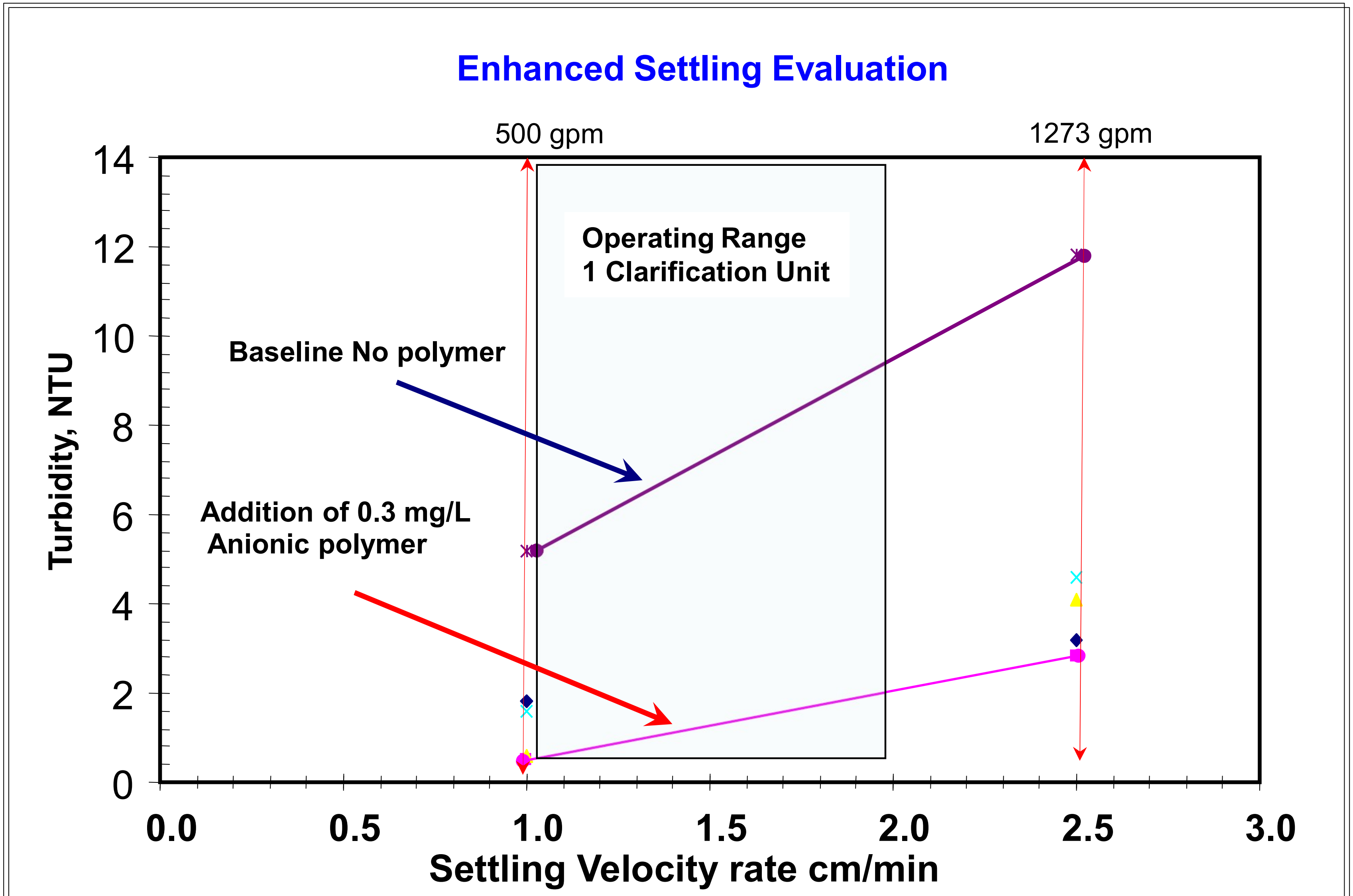
Jar Test: Settling Rates



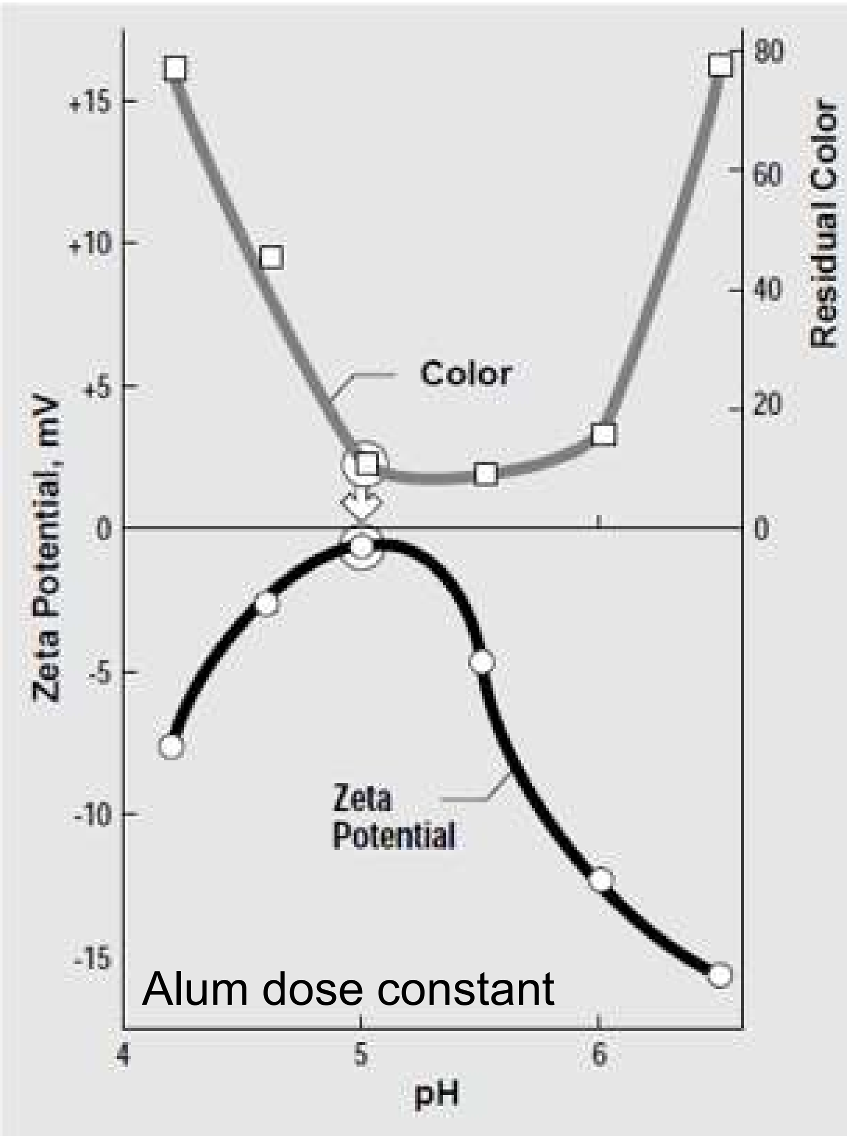
Jar Test: Settling Rates



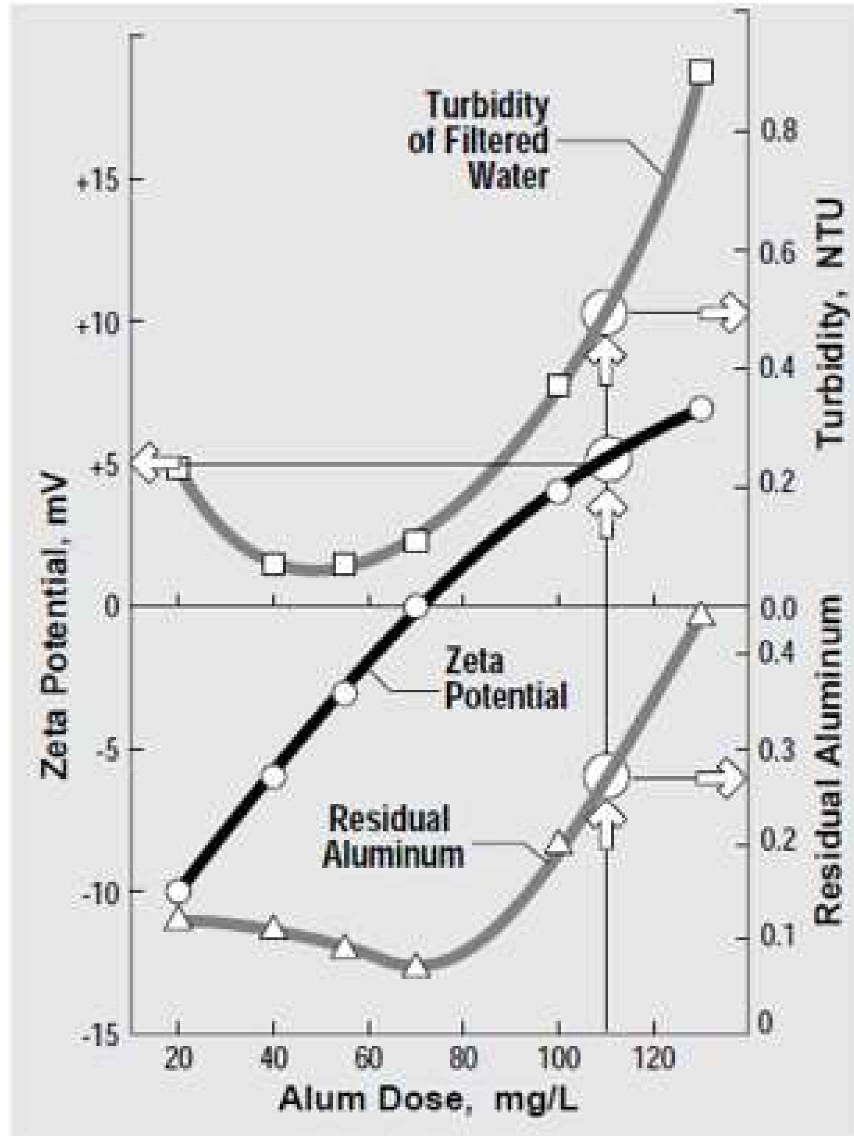
Jar Test Results



Effect of pH on Zeta Pot.



Effect of Overdosing



Source: Everything you wanted to know about Coagulation & Flocculation, Zeta-Meter, Inc.