Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

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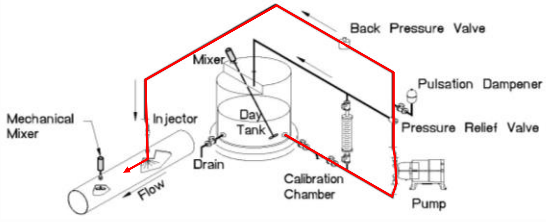
Coagulation

Typical coagulant feed system



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Chemicals must meet ANSI/NSF 60

Make sure product meets ANSI/NSF Standard 60 and you are not exceeding maximum use.

Solvay Dense Soda Ash (Sodium Carbonate, Anhydrous)

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Epichlorohydrin & Acrylamide (ANSI/NSF 60)

1. Do not exceed maximum use identified by ANSI/NSF 60.
2. NSF, UL, and WQA all specify a maximum use that ensures compliance.
3. A form will be mailed out each year to help you meet the reporting requirements of OAR 333-061-0030(7)

(7) Acrylamide and Epichlorohydrin. For every public water system, the water supplier must certify annually to the state in writing, using third party certification approved by the state or manufacturer's certification, that when acrylamide and epichlorohydrin are used in drinking water systems, the combination, or product, of dose and monomer level does not exceed the levels specified as follows:
(a) Acrylamide: 0.05 percent dosed at 1 ppm or equivalent.
(b) Epichlorohydrin: 0.01 percent dosed at 20 ppm or equivalent.

Stat. Auth.: ORS 448.131
Stats. Implemented: ORS 448.131, 448.150

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Epichlorohydrin & Acrylamide (ANSI/NSF 60)

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Epichlorohydrin and Acrylamide Usage
Certification Form

System ID: OR41____ Reporting Period/Year: ____
System Name: ____ County: ____

I certify that polymer(s) ☐ was ☐ was not *(Check box that applies)* used for treatment of drinking water during the reporting period.

If a polymer was used, it may have contained epichlorohydrin and acrylamide. In accordance with OAR 333-061-0030(7), ***I hereby certify*** that the product identification, listing, and maximum dosages applied during the reporting period were as follows:

Polymer #1 Name: ____ Manufacturer: ____
Certification organization listing this product in compliance with NSF Standard 60 (check one):
☐ NSF ☐ UL ☐ WQA ☐ Other ____ ☐ None*
Allowable maximum use dosage in product listing: ____ mg/L (ppm)
Actual maximum dosage applied during reporting period: ____ mg/L (ppm)

*OAR 333-061-0087(6) - Products added to public water systems must meet requirements of NSF Standard 60 or equiv.

A form will be mailed out each year to help you meet the reporting requirements of OAR 333-061-0030(7)

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Epichlorohydrin & Acrylamide (ANSI/NSF 60)

1. Do not exceed maximum use identified by ANSI/NSF 60.

http://info.nsf.org/Certified/PwsChemicals/

2. Beware of product name changes and loss of NSF-60 certification.

Polyamines[PY]

Trade Designation	*Product Function*	*Max Use*
Superfloc 730G	Coagulation & Flocculation	20mg/L
Superfloc 781G	Coagulation & Flocculation	20mg/L
Superfloc C-568	Coagulation & Flocculation	20mg/L
Superfloc C-572	Coagulation & Flocculation	20mg/L
Superfloc C-573	Coagulation & Flocculation	20mg/L
Superfloc C-573 PWG	Coagulation & Flocculation	20mg/L
Superfloc C-576	Coagulation & Flocculation	22mg/L
Superfloc C-577	Coagulation & Flocculation	20mg/L
Superfloc C-581	Coagulation & Flocculation	20mg/L
Superfloc C-583	Coagulation & Flocculation	20mg/L
Superfloc C568	Coagulation & Flocculation	20mg/L
Superfloc C578	Coagulation & Flocculation	20mg/L

[PY] Polyamines Certified by NSF International comply with 40 CFR 141.111 requirements for percent monomer and dose.

40 CFR 141.111 is the federal rule citation for acrylamide and epichlorohydrin addressed under -0030(7) in OAR.

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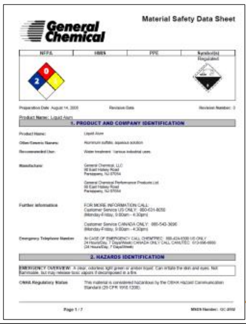
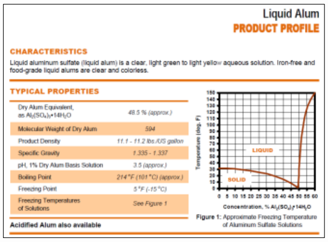
Maintain current MSDS & Product Specs

Maintain current MSDS and product specification sheets





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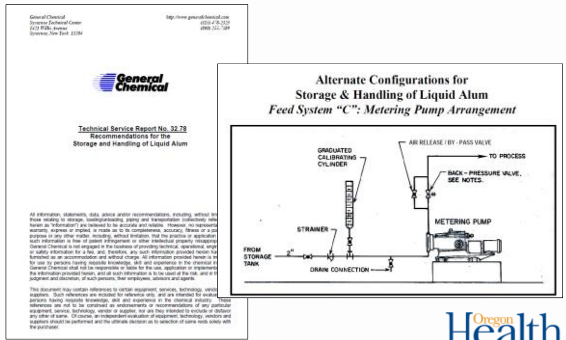
Store and Handle Per Manufacturer



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Clearly Label Tanks

City of Vernonia, 2010

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Coagulation

- Objectives depend on raw water quality
- Most particles found in source waters are negatively charged (e.g., clay, organics, algae cells)
  - Particles repel each other
- Coagulant(s) added to destabilize particles (neutralize negative charge)
  - Neutralized particles collide and build floc

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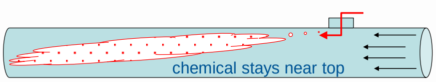
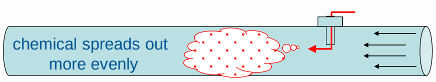
Coagulation Depends on Mixing

Injection quills can help evenly disburse chemical and improve mixing





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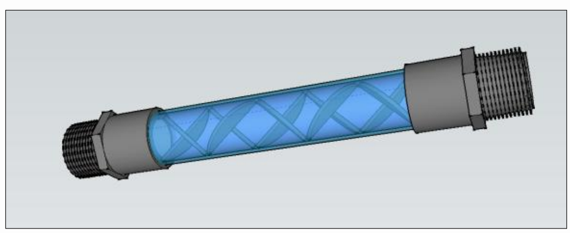
Coagulation Depends on Mixing

- Static mixers have veins or "elements" that promote mixing.
- The more water is pushed through a static mixer, the higher the head loss and better mixing you have.



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Factors Affecting Coagulation

- Dosage: determined by jar test for optimum qualities of floc: (size, settling rate).
- Mixing: Mechanical or static. Need to rapidly mix chemicals.
- Alkalinity: 50 mg/l or less can shift pH downward.
- Temperature: Colder water slows coagulation.
- Color: Pre-oxidation may be required.
- Turbidity: Changing conditions require more frequent jar tests.

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Coagulants

- Aluminum sulfate (alum): very common, only effective in narrow pH range (typically pH = 6.0 – 7.4). Consumes about 0.5 mg/l alkalinity for every 1 mg/l of alum dosed.
- Ferric chloride: More expensive, but works in wider pH range (pH = 4.0 – 11.0). Consumes about 1 mg/l alkalinity for every 1 mg/l ferric chloride dosed.
- Poly aluminum chloride (PACL): not affected by pH, doesn't change pH, works well with low alkalinity, leaves less sludge because dosage is low.
- Aluminum Chlorohydrate (ACH): similar to PACL.

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Flocculation

- Objectives depend upon subsequent processes (sedimentation, type of filtration, etc.)
- Generally the objective is to:
  - Develop settleable or filterable floc particle.
  - Optimize flocculation detention time and energy

Typical Hydraulic Detention Times		Hydraulic Detention Time
Single-Stage	Temp <= 5°C	30 minutes
	Temp > 5°C	25 minutes
Multiple Stages	Temp <= 5°C	20 minutes
	Temp > 5°C	15 minutes

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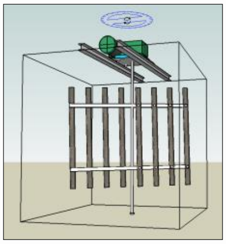
Flocculation

Flocculation mixing can be accomplished using paddle-wheel flocculators, mounted horizontally or vertically.



Flocculation paddles - photo from 2007 CPE at Sweethome, OR

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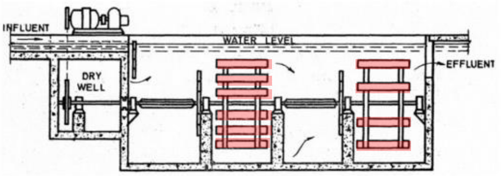
Flocculation

Flocculation usually involves multiple stages of progressively lower mixing intensity.

This can be accomplished by having fewer paddle boards in the next stage as shown below.



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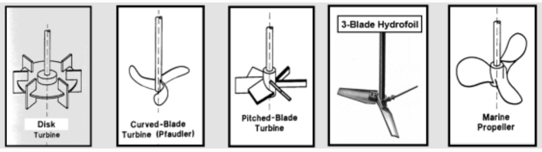
Flocculation

Mixing can also be accomplished using a variety of turbines and hydrofoils.



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Flocculation

Mixing can also be accomplished hydraulically, using baffle walls

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Common Coagulants and Flocculants

- Several types of coagulants available (often source of confusion):
  - Metal salts (alum and ferric)
  - Blended Products: Polyaluminum Chloride (PACl), Aluminum Chlorohydrate (ACH)
  - Polymers:
    - Cationic
    - Anionic
    - Non-ionic

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Alum and Ferric Considerations

- Know the product strength:
  - Alum: 48 %wt ~5.4 lb per gal
  - Ferric chloride: 30 %wt ~3.4 lb per gal
- Don't forget alkalinity:
  - Every 1 mg/L alum consumes ~0.5 mg/L alkalinity
  - Every 1 mg/L ferric chloride consumes ~0.75 mg/L alkalinity
  - Maintain 5 to 10 mg/L alkalinity or add alkalinity (e.g., lime, soda ash)

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Blended Product Considerations (e.g., PACl)

- Contains either aluminum or iron.
- Product strength typically same as product weight.
  - Equivalent dosages determined by % metal concentration (Al_2O_3, Fe) if known.
- Basicity is term used to describe product's relative charge.
  - Higher basicity products have higher positive charge.
- These products typically consume less alkalinity (i.e., less impact on pH).
  - Higher basicity products consume less alkalinity (i.e., 50% basicity product would consume half the alkalinity of equivalent alum dose).

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Polymer Considerations

- Consist of long chain organic molecules.
  - Described by their molecular weight and charge density.
- Minimal effect on alkalinity.
- Product strength typically same as product weight (e.g. assume 100% strength).
- Provide multiple functions:
  - Coagulant (cationic)
  - Flocculant (anionic)
  - Filter aid (cationic, anionic, or non-ionic ⇒ all at <u>very low</u> dosages: < 0.1 mg/L)

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Dose and Chemical Feeder Settings

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Would you be able to answer the following questions?

What was the coagulant dose when we exceeded 1 NTU?

Did we exceed the maximum recommended dose (NSF-60)?

Which coagulant costs less given the differences in aluminum content?

Will we need new feed pumps if we increase plant capacity?

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Dose and Chemical Feeder Settings

You will need…

1) Dosage required for good water quality (jar test, target pH, target chlorine residual, etc.)
2) Chemical pump feed rate required for desired dose.
3) Product strength (density x % concentration).

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Approach

1. Establish a desired chemical dose (jar testing results are of little value if they can't be applied in plant!).
2. Calculate the coagulant feed pump setting to achieve the desired dose.
3. Adjust the coagulant feed pump based on a calibration curve or pump flow rate test with graduated cylinder.

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Conversion Factors

Good conversion factors to know:

- 1 lb = 454 grams = 0.454 kg (2.2 lb/kg)
- 1% = 10,000 mg/l (Assumes specific gravity = 1)

About water:

- Specific gravity of water = 1.0 (varies with temp)
- 1 gallon of water weighs 8.34 lbs (8.344 lbs at its densest)
- 1 ml of water weighs 1 gram
- 1 US gallon = 231 cubic inches = 3.785 liters (3.78541)

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About the "pounds formula"

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = 8.34\ x\ dose\ \left(\frac{mg}{liter}\right) x\ flow\ \left(\frac{MG}{day}\right)$$

1. Can be used for liquid products (can be used as is if product has a specific gravity of 1 and is 100% pure – e.g. water. Chlorine is generally considered to have a SG of 1. Polymers are generally treated as 100% "pure".)
2. Can be used for dry products (assumes 100% active ingredient).

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More about the "pounds formula"

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = 8.34\ x\ dose\ \left(\frac{mg}{liter}\right) x\ flow\ \left(\frac{MG}{day}\right)$$

1. Can be used for liquid products (can be used as is if product has a specific gravity of 1 and is 100% pure)
2. Can be used for dry products (assumes 100% active ingredient).
3. 8.34 is a factor resulting from a "simple" conversion of units:

$$\left[\frac{1\ lb}{454\ \cancel{grams}}\right] x \left[\frac{1\ \cancel{gram}}{1{,}000\ mg}\right] x \left[\frac{3.7854\ liters}{\cancel{gallon}}\right] x \left[\frac{1{,}000{,}000\ \cancel{gallons}}{MG}\right]$$

$$= 8.34\ \frac{lb{-}liter}{mg{-}MG} = \frac{8.34\ lbs}{MG\left(\frac{mg}{liter}\right)}$$

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Feed rate in gallons/day (GPD)

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right)\ x\ flow\ \left(\frac{\cancel{MG}}{day}\right)$$

Convert to gpd using density

If the feed rate needs to be in volume (e.g. gallons/day), you need to factor in the density of the product (weight/volume).

1. A volume (e.g. gallon or ml) of product may be literally weighed to determine this.
2. Or you could use the specific gravity of the product, which is typically available from the product specification sheet.

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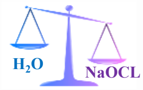
Density

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right)\ x\ flow\ \left(\frac{\cancel{MG}}{day}\right)$$

Density

1. The density of a substance is the weight for a given unit volume. For example water has a density of 8.34 lbs/gallon (1 g/ml).
2. Specific gravity (Sp. Gravity or SG) is the density of a liquid substance relative to the density of water. Water has a SG = 1.0.

Example: 12.5% sodium hypochlorite (NaOCL) has a SG of around 1.2, therefore, the density of the chlorine = SG of chlorine x density of water.



$$Density\ of\ 12.5\%\ NaOCL = 1.2\ x\ 8.34 = 10\ lbs/gallon$$

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Density and GPD

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right)\ x\ flow\ \left(\frac{\cancel{MG}}{day}\right)$$

Convert to gpd

$$Feed\ rate\ (gpd) = \frac{\left[Feed\ rate\ \left(\frac{lb}{day}\right)\right]}{\left[SG\ x\ 8.34\ \frac{lb}{gal}\right]}$$

Or combined…

$$Feed\ rate\ (gpd) = \frac{\left[\frac{\cancel{8.34\ lbs}}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\ \left(\frac{\cancel{MG}}{day}\right)\right]}{\left[SG\ x\ 8.34 \frac{\cancel{lb}}{gal}\right]}$$

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% Concentration

How does % concentration factor in?

If the product is diluted in any way, this also needs to be factored in. Generally this is expressed as a % concentration (e.g. 12.5% sodium hypochlorite, 50% caustic, or 48.5% alum).

Divide the feed rate by the product % concentration (converted to a decimal by dividing by 100%) as shown below:

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{\left[\frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\ \left(\frac{\cancel{MG}}{day}\right)\right]}{\left[\frac{\cancel{\%}\ strength}{100\cancel{\%}}\right]}$$

$$Feed\ rate\ (gpd) = \frac{\left[\frac{\cancel{8.34\ lbs}}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ dose\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\ \left(\frac{\cancel{MG}}{day}\right)\right]}{\left[SG\ x\ 8.34 \frac{\cancel{lb}}{gal}\right] x \left[\frac{\cancel{\%}\ strength}{100\cancel{\%}}\right]}$$

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Example – "pounds formula"

Example: What feed rate in (lbs/day, gpd, and ml/min) is needed for 0.5 mg/l dose of 12.5% NaOCL (SG = 1.2) at a flow rate of 1 MGD?

$$1)\ Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ 0.5\ \left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ 1\ \left(\frac{\cancel{MG}}{day}\right)\ x\ \left(\frac{1}{0.125}\right) = \boxed{33.36\ \frac{lbs}{day}}$$

Divide by decimal equivalent of 12.5% strength

$$2)\ Feed\ rate\ (gpd) = \frac{\left[33.36\left(\frac{lbs}{day}\right)\right]}{\left[1.2\ x\ 8.34\frac{lbs}{gal}\right]} = \boxed{3.33\ gpd}$$

Account for SG of 1.2

$$3)\ Feed\ rate\ \left(\frac{ml}{min}\right) = \left(\frac{1\ \cancel{day}}{1{,}440\ min}\right) x\ 3.33\ \left(\frac{\cancel{gallons}}{\cancel{day}}\right) x\ 3.7854\ \left(\frac{\cancel{liters}}{\cancel{gallon}}\right) x\ 1{,}000\ \left(\frac{ml}{\cancel{liter}}\right)$$

$$= \boxed{8.75\ ml/min}$$

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Coagulant Feed Rate - Summary Liquid Products

- Convert desired dose to required feed rate:
  - Dose (ppm) x 8.34 lb/gal x flow (MGD) = feed rate (lb/day)…may need to divide by % strength
  - Feed rate (lb/day) ÷ product density (lb/gal) ÷ % strength = feed rate (gal/day)
    - Product density = product weight per unit volume (liquid alum ~ 11.1 lb/gal)
    - Sometimes the term "product strength" is used to combine the terms of product density times % strength (liquid alum ~ 11.1 lb/gal x 48% alum = 5.3 lb/gal)

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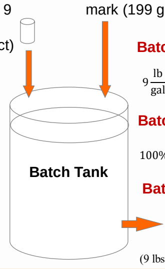
Example Product Strength Calculation for a Diluted Polymer

Add 1 gallon of polymer weighing 9 lb/gal (density of 100% pure product)

Fill batch tank with water to 200-gallon mark (199 gal of water at 8.34 lb/gal)



Batch Tank Density =

$$9\frac{lb}{gal}\left(\frac{1}{200}\right)+8.34\frac{lb}{gal}\left(\frac{199}{200}\right)=8.3433\ lb/gal$$

Batch Tank Concentration (%wt/wt) =

$$100\%\ x\left(\frac{1\ gallon\ x\ 9\ lb/gal}{199\ gallons\ x\ 8.34\ lb/gal}\right)=0.5423\%$$

Batch Tank Concentration (lb/gal) =

$$8.3433\frac{lb}{gal}x\frac{0.5423\%}{100\%}=0.045\ lbs\ of\ polymer/gal$$

(9 lbs polymer / 200 gal = 0.045 lb/gal)

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Another way to calculate density in this example:

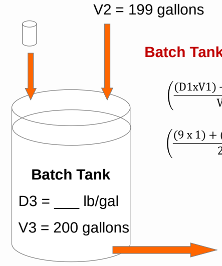
D1·V1 + D2·V2 = D3·V3 ====> D3 = (D1·V1 + D2·V2) / V3

D1 = 9 lb/gal

V1 = 1 gallon

D2 = 8.34 lb/gal

V2 = 199 gallons



Batch Tank Density =

$$\left(\frac{(D1xV1)+(D2xV2)}{V3}\right)=D3$$

$$\left(\frac{(9\ x\ 1)+(8.34\ x\ 199)}{200}\right)=8.3433\ lbs/gallon$$

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Can you calculate concentration the same way? Yes!

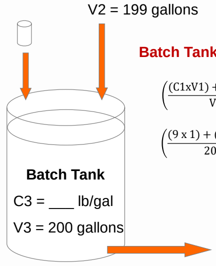
C1·V1 + C2·V2 = C3·V3 ====> C3 = (C1·V1 + C2·V2) / V3

C1 = 9 lb/gal

V1 = 1 gallon

C2 = 0 lb/gal

V2 = 199 gallons



Batch Tank Concentration =

$$\left(\frac{(C1xV1)+(C2xV2)}{V3}\right)=C3$$

$$\left(\frac{(9\ x\ 1)+(0\ x\ 199)}{200}\right)=0.045\ lbs\ of\ polymer/gallon$$

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Another example with chlorine:

C1·V1 + C2·V2 = C3·V3 ====> C3 = (C1·V1 + C2·V2) / V3

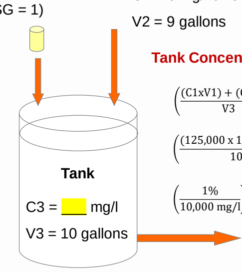
C1 = 125,000 mg/l chlorine (12.5%)

(assumes SG = 1)

V1 = 1 gallon

C2 = 0 mg/l chlorine

V2 = 9 gallons



Tank Concentration =

$$\left(\frac{(C1xV1)+(C2xV2)}{V3}\right)=C3$$

$$\left(\frac{(125{,}000\ x\ 1)+(0\ x\ 9)}{10}\right)=12{,}500\ mg/l$$

$$\left(\frac{1\%}{10{,}000\ mg/l}\right)x\ 12{,}500\frac{mg}{l}=1.25\%$$

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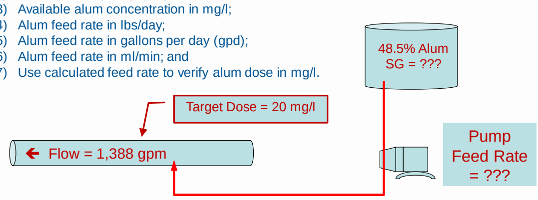
One more example – Alum (it just got real!)

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight (density) of 10.9 lbs/gal.

Solve for:

1) Plant flow in MGD;
2) Alum specific gravity (SG);
3) Available alum concentration in mg/l;
4) Alum feed rate in lbs/day;
5) Alum feed rate in gallons per day (gpd);
6) Alum feed rate in ml/min; and
7) Use calculated feed rate to verify alum dose in mg/l.



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One more example - Alum

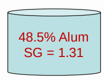
Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow in MGD;
2) Alum specific gravity (SG);

$$1)\ Plant\ flow=1{,}388\ \frac{gallons}{minute}\ x\left(\frac{1\ MG}{1{,}000{,}000\ gallons}\right)x\left(\frac{1{,}440\ minutes}{1\ day}\right)=2\ \frac{MG}{day}$$

$$2)\ Alum\ SG=10.9\left(\frac{lb}{gal}\right)x\left(\frac{1\ gal\ water}{8.34\ lbs}\right)=1.30695\simeq 1.31$$



$$100\%\ water\ weighs\left(\frac{1\ gram}{1\ ml}\right)\Rightarrow\left(\frac{1\ gram}{1\ ml}\right)x\left(\frac{1\ lb}{454\ gram}\right)x\left(\frac{3.78541\ l}{1\ gallon}\right)x\left(\frac{1{,}000\ ml}{l}\right)=8.338\ lbs/gallon$$

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 1st way uses the relationship of 1% = 10,000 mg/l, which is based on the weight of water (SG=1) where 1 ml weighs 1 gram. This calculation is shown below:

48.5% Alum
SG = 1.31

$$100\%\ water\ weighs \left(\frac{1\ gram}{1\ ml}\right) \Rightarrow \left(\frac{1\ \cancel{gram}}{1\ \cancel{ml}}\right) x \left(\frac{1{,}000\ mg}{1\ \cancel{gram}}\right) x \left(\frac{1{,}000\ \cancel{ml}}{l}\right) = 1{,}000{,}000\ mg/l$$

$$1\%\ of\ the\ weight\ of\ water = 1\%\ x \left(\frac{1{,}000{,}000\ mg}{100\ \cancel{\%}}\right) = 10{,}000\ mg/l$$

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 1st way uses the relationship of 1% = 10,000 mg/l, which is based on the weight of water (SG=1) where 1 ml weighs 1 gram. This calculation is shown below:

48.5% Alum
SG = 1.31

$$Available\ alum\ concentration\ in\ \frac{mg}{l} = SG\ x\ \%\ concentration\ x \left(\frac{10{,}000\ mg/l}{1\ \%}\right)$$

$$Available\ alum\ concentration = 1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \cancel{\%}}\right) = \boxed{635{,}350\ mg/l}$$

Remember, we have to account for liquid alum (which is a dilution containing 48.5% alum in water)

Oregon Health Authority

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 2nd way uses the % concentration, density of the 48.5% alum, and a series of unit conversions

48.5% Alum
SG = 1.31

$$\left(\frac{48.5\cancel{\%}}{100\cancel{\%}}\right) x \left(\frac{10.9\ \cancel{lbs}}{\cancel{gallon}}\right) x \left(\frac{454\ \cancel{g}}{1\ \cancel{lb}}\right) x \left(\frac{1{,}000\ mg}{1\ \cancel{g}}\right) x \left(\frac{1\ \cancel{gallon}}{3.7854\ l}\right) = \boxed{634{,}034\ mg/l}$$

$$1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \cancel{\%}}\right) = 635{,}350\ mg/l$$

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lbs/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 2nd way uses the % concentration, density of the 48.5% alum, and a series of unit conversions…

48.5% Alum
SG = 1.31

$$\left(\frac{48.5\cancel{\%}}{100\cancel{\%}}\right) x \left(\frac{10.9\ \cancel{lbs}}{\cancel{gallon}}\right) x \left(\frac{454\ \cancel{g}}{1\ \cancel{lb}}\right) x \left(\frac{1{,}000\ mg}{1\ \cancel{g}}\right) x \left(\frac{1\ \cancel{gallon}}{3.7854\ l}\right) = \boxed{634{,}032\ mg/l}$$

$$1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \cancel{\%}}\right) = 635{,}350\ mg/l$$

Why 0.2% difference? Rounding errors (1.31 vs 1.30695)

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate in lbs/day;

$$Feed\ rate \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)}\ x\ 20 \left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ 2 \left(\frac{\cancel{MG}}{day}\right) = \boxed{333.6\ \frac{lbs}{day}}$$

Pump Feed Rate = 333.6 lbs/day

Remember, this is the feed rate in lbs of dry alum per day (assumes 100% strength and does not divide by the decimal equivalent of 48.5% strength)

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;

$$Feed\ rate\ (gpd) = \frac{\left[333.6 \left(\frac{lbs}{day}\right)\right]}{\left[\left(\frac{48.5\cancel{\%}}{100\cancel{\%}}\right) x\ 1.31\ x\ 8.34 \frac{lbs}{gal}\right]} = \frac{\left[333.6 \left(\frac{\cancel{lbs}}{day}\right)\right]}{\left[5.2988 \frac{\cancel{lbs}}{gal}\right]} = \boxed{63\ \frac{gal}{day}}$$

Divide by decimal equivalent of 48.5% strength

Account for SG of 1.31

Pump Feed Rate = 63 gpd

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;
6) Alum feed rate in ml/min;

$$Feed\ rate\left(\frac{ml}{min}\right)=\left(\frac{1\ \cancel{day}}{1{,}440\ min}\right)x\ 63\left(\frac{\cancel{gallons}}{\cancel{day}}\right)x\ 3.7854\left(\frac{\cancel{liters}}{\cancel{gallon}}\right)x\ 1{,}000\left(\frac{ml}{\cancel{liter}}\right)$$

$$Feed\ rate = \boxed{165\ ml/min}$$

Pump Feed Rate = 165 ml/min

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One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;
6) Alum feed rate = 165 ml/min;
7) Use calculated feed rate to verify alum dose in mg/l.

$$C1Q1 + C2Q2 = C3Q3$$

$$\left(\frac{C1Q1 + C2Q2}{Q3}\right) = C3$$

48.5% Alum SG = 1.31

Target Dose = 20 mg/l

C3 = ____ mg/l Q3 = 2,000,063 gpd ← Flow C2 = 0 mg/l Q2 = 2,000,000 gpd

Pump Feed Rate = 63 gpd

$$\left(\frac{(634{,}032\ x\ 63) + (0\ x\ 2{,}000{,}000)}{2{,}000{,}063}\right) = \boxed{19.97\ mg/l}$$

C1 = 634,032 mg/l
Q1 = 63 gpd

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Determination of Coagulant Feed Rate Dry Products

- Convert dose to feed rate:
  - Dose (mg/l) x 8.34 lb/gal x flow (MGD) = feed rate (lb/day)
- Dry feeders:
  - Calibrate from grab sample(s) over timed period.
    - Weigh sample(s) and express as weight per unit time.
    - Develop calibration curve based on multiple grab samples at different feeder settings.

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Approach

1. Establish a desired chemical dose (jar testing results are of little value if they can't be applied in plant!).
2. Calculate the coagulant feed pump setting to achieve the desired dose.
3. Adjust the coagulant feed pump based on a calibration curve or pump flow rate ("drawdown") test with graduated cylinder.

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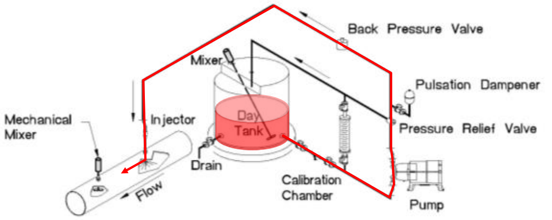
Pump Flow

Normal coagulant flow path



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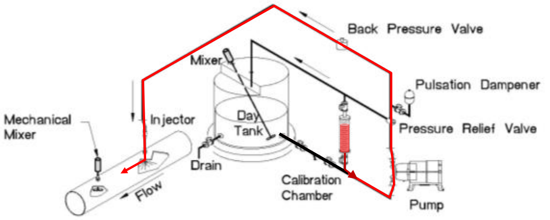
Pump Flow Rate ("Drawdown") Test

Coagulant flow during pump drawdown test



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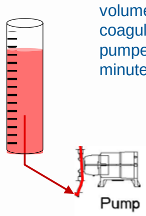
Pump Flow Rate ("Drawdown") Test

Coagulant flow during pump drawdown test

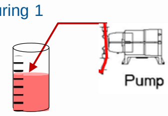
Either:

1. Fill the calibration column and allow pumping coagulant out of column.
2. Measure what volume of coagulant is pumped during 1 minute.



or:

1. Pump into a graduated cylinder.
2. Measure what volume of coagulant is pumped during 1 minute.



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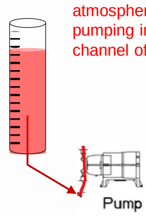
Pump Flow Rate ("Drawdown") Test

Coagulant flow during pump drawdown test

Either:

Fill the calibration column and allow pumping coagulant out of column.

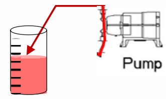
Better when normally pumping into pipe under pressure (backpressure during normal operation will still be simulated under this drawdown scenario)



or:

Pump into a graduated cylinder.

Better when normally pumping flocculants or filter aids against atmospheric pressure such as pumping into the top and/or inlet channel of floc or filter basins.



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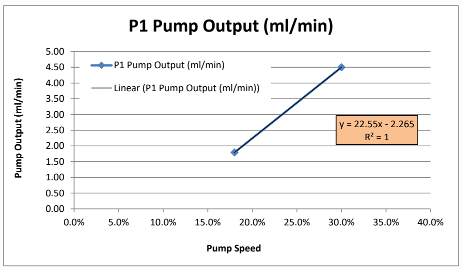
Pump Flow Rate ("Drawdown") Test

Coagulant flow during pump drawdown test

Tabulate and/or plot results



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Pump Flow Rate ("Drawdown") Test

Coagulant flow during pump drawdown test

You can have a calibration column for each pump or use the same calibration column for two pumps (a primary pump and a backup for example), provided they pump the same chemical.

City of Corvallis, 2009

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Example – Does current dose match what you think you are dosing?

Equation 1:

$$\text{Feed Rate, mL/min} = \frac{\text{(Sample Volume) mL}}{\text{(Sample Time) min}}$$

Equation 2:

$$\text{Feed Rate, gal/day} = \frac{\text{(Feed Rate) mL}}{\text{min}} \text{ x } \frac{\text{gal}}{\text{3,785 mL}} \text{ x } \frac{\text{1,440 min}}{\text{day}}$$

Equation 3:

Product strength = (8.34 lbs/gal) x (product specific gravity) x (product % strength expressed as a decimal)

$$\text{Feed Rate, lb/day} = \frac{\text{(Feed Rate) gal}}{\text{day}} \text{ x } \frac{\text{(Product Strength) lb}}{\text{gal}}$$

Equation 4:

$$\text{Dose, mg/L} = \frac{\text{(Feed Rate) lb}}{\text{day}} \text{ x } \frac{\text{day}}{\text{(Flow) MG}} \text{ x } \frac{\text{gal}}{\text{8.34 lb}}$$

Pump 1 Dosage Check

Variable	Result	Units	Comments
Reported plant flow	57	gpm	
Reported plant flow	0.082	MGD	(57 gpm)
Feed Rate	4.5	ml/min	Drawdown Test (Equation 1)
Feed Rate	1.71	gal/day	(Equation 2)
Product Strength (wt/wt%)	100	%	(100% = 1.00)
Product Specific Gravity	1.24	SpGr	100% PASS C-X, SpGr=1.24
Product Strength (Density)	10.34	lbs/gal	= 8.34 lbs/gallon x 1.24 x 1.00
Feed Rate	17.71	lbs/day	(Equation 3)
Calculated plant dosage	25.85	mg/L	(Equation 4)
Reported plant dosage	26	mg/L	

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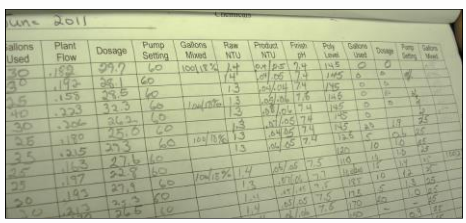
Homework Assignment

- Develop standard operating procedure (SOP) for plant-specific approach to setting coagulant feed.



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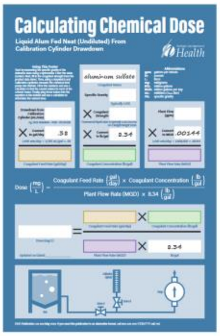
Homework Assignment



You may be able to find an SOP online – just be sure you understand how it works.

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Coagulation Optimization
Potential Special Studies

- Coagulant type and dose for given water quality (i.e., turbidity, alkalinity, temp., TOC, algae).
- Rapid mix (ideal: high energy & short time).
- Coagulation pH (TOC removal).
- Effect of coagulant aids.
- Addition of alkalinity (e.g., lime, soda ash).
- Effect of pre-oxidants (i.e., chlorine, $KMnO_4$).
- Others?

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Flocculation Optimization
Possible Special Studies

- Mixing energy (use jar test calibration studies to assess changes in mixing speed).
- Basin short-circuiting (baffle addition?).
- Floc breakup at transition zones.
- Use of flocculant aids.
- Others?

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Jar Testing

- Advantages:
  - Can be used to optimize both coagulation and flocculation
  - Available in most plants
  - Proven process control tool
  - Effective training tool (special studies)
- Disadvantages:
  - Matching jar test performance to plant
  - Jar test procedure intimidating for some plant staff

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Jar Testing

Equipment needed

1. 300-RPM jar tester
2. 2-L square jars (x6)
3. 10-ml pipette
4. 1.0, 3.0, 12.0 ml syringes (x6)
5. Plastic cups (x6)
6. 100-ml Volumetric flask
7. Turbidimeter w/6 sample vials
8. Coagulant

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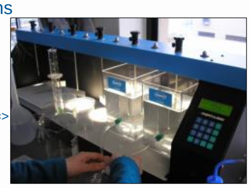
Jar Testing

Jar testers come in a variety of forms

<= 4-jar (portable)

Programmable =>



<= 6-jar =>

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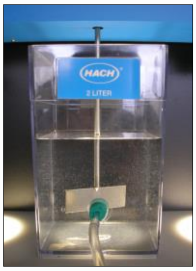
Jar Testing

Jars can be 2-L square or 1-L round

bulkhead fitting
(works better)



cork" stopper
(tends to dislodge)

no good way to sample consistently

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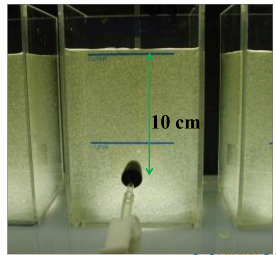
Advantages of the 2-Liter Square Jars

- Better mixing
- Mixing curve available
- Better insulating properties (reduces water temperature changes)
- More water for testing (2L versus just 1 L)
- Standard sampling location used to determine settling velocity



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Standard Jar Test Procedure

1. Prepare chemical stock solutions or feed "neat" using micro-syringes.
2. Decide on jar chemical doses and volumes.
3. Collect water sample and fill jars.
4. Start mixer and adjust for rapid mix.
5. Add chemicals in same sequence as plant.
6. Adjust mixer speed to simulate flocculation.
7. Stop mixer after floc time and settle.
8. Sample jars and test.

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Jar Test Basics

Preparing Stock Solutions

- Stock solutions can be made to test polymers, pre-oxidants, and pH adjustment chemicals.
- Determine the dose range to be tested:
  - Use historical data, vendor recommendations, raw water quality.
- Select the stock solution concentration.
- Make stock solution using a volumetric flask and distilled water.
- Make dilute stock solutions on a daily basis for solutions < 0.1% or at least weekly for solutions > 0.1%.

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Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	0.05	500
0.50	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

$$\% \text{ wt} = \left(\frac{\text{Desired Dosage in } \frac{mg}{l} \text{ x } 2{,}000 \text{ ml jar volume}}{1 \text{ ml of stock solution added to each } 2\text{–}L \text{ jar x } 10{,}000 \text{ mg}/l/1\%}\right)$$

$$\text{Mg/l} = \% \text{ wt x } \left(\frac{10{,}000 \text{ mg}/l}{1\%}\right)$$

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Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	0.05	500
0.50	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

Example: For every 1 mL of a 2% stock solution (20,000 mg/l) added to a 2-L jar, the coagulant concentration in the jar increases by 10 mg/l (add 2 ml for 20 mg/l, 3 ml for 30 mg/l, etc.)

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Example: 2% alum stock solution

C1·V1 + C2·V2 = C3·V3 ===> V1 = (C3·V3 - C2·V2) / C1

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
	0.01	100
	0.05	500
	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

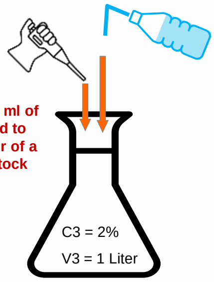
C1 = 48.5% alum (SG = 1.35)

V1 = ? ml

C2 = 0% alum (distilled water, SG = 1)

V2 = 1 Liter – V1

How many ml of alum to add to make 1 liter of a 2% alum stock solution?



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Example: 2% alum stock solution

C1·V1 + C2·V2 = C3·V3 ===> V1 = (C3·V3 - C2·V2) / C1

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	% wt	Mg/L
	0.01	100
	0.05	500
	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

C1 = 48.5% alum (SG = 1.35)

V1 = ? ml

Alum strength – method 1:

$$C1 = \left(\frac{10{,}000\ mg/l}{1\%}\right) x\ 48.5\%\ x\ 1.35\ SG$$

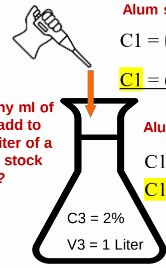
$$\underline{C1 = 654{,}750\ mg/l}$$

Alum strength – method 2:

$$C1 = 8.34\ lb/gallon\ x \left(\frac{48.5\%}{100\%}\right) x\ 1.35\ SG$$

$$C1 = 5.46\ lb/gallon$$

How many ml of alum to add to make 1 liter of a 2% alum stock solution?



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Example: 2% alum stock solution

C1·V1 + C2·V2 = C3·V3 ===> V1 = (C3·V3 - C2·V2) / C1

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
	0.01	100
	0.05	500
	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

C1 = 48.5% alum (SG = 1.35) = 654,750 mg/l
5.46 lbs/gallon

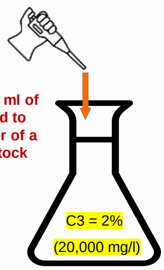
V1 = ? ml

Volumetric Flask Concentration = 2% (SG ~ 1.0)

$$C3 = \left(\frac{10{,}000\ mg/l}{1\%}\right) x\ 2\%$$

$$C3 = \underline{20{,}000\ mg/l}$$

How many ml of alum to add to make 1 liter of a 2% alum stock solution?



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Example: 2% alum stock solution

C1·V1 + C2·V2 = C3·V3 ===> V1 = (C3·V3 - C2·V2) / C1

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
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	0.05	500
	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

C1 = 48.5% alum (SG = 1.35) = 654,750 mg/l
5.46 lbs/gallon

V1 = ? ml

C2 = 0% alum (distilled water, SG = 1)

V2 = 1 Liter – V1

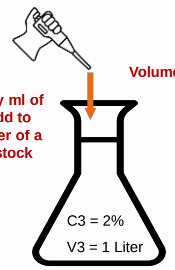
Volume of 48.5% alum to add to flask – method 1:

$$V1 = \left(\frac{(C3V3) - C2V2))}{C1}\right)$$

$$V1 = \left(\frac{20{,}000\ mg/l\ x\ 1\ liter) - 0}{654{,}750\ mg/l}\right)$$

$$\underline{V1 = 0.030546\ liters = 30.55\ ml}$$

How many ml of alum to add to make 1 liter of a 2% alum stock solution?



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Example: 2% alum stock solution

C1·V1 + C2·V2 = C3·V3 ===> V1 = (C3·V3 - C2·V2) / C1

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
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	0.05	500
	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

C1 = 48.5% alum (SG = 1.35) = 654,750 mg/l
5.46 lbs/gallon

V1 = 30.55 ml

C2 = 0% alum (distilled water, SG = 1)

V2 = 1 Liter – V1

Volume of 48.5% alum to add to flask – method 1:

$$V1 = \left(\frac{(C3V3) - C2V2))}{C1}\right)$$

$$V1 = \left(\frac{20{,}000\ mg/l\ x\ 1\ liter) - 0}{654{,}750\ mg/l}\right)$$

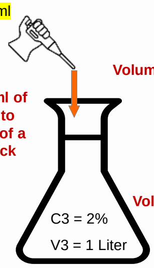
$$\underline{V1 = 0.030546\ liters = 30.55\ ml}$$

Volume of 48.5% alum to add to flask – method 2:

$$V1 = \left(\frac{2\%\ x\ 1{,}000\ ml\ in\ flask\ x\ 8.34\ lb/gal)}{(100\ x\ 5.46\frac{lb}{gal}\ product\ strength)}\right)$$

$$\underline{V1 = 30.55\ ml}$$

How many ml of alum to add to make 1 liter of a 2% alum stock solution?



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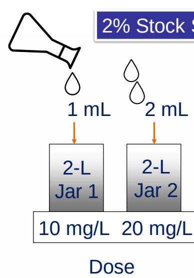
Example: 2% alum stock solution

2% Stock Solution *



Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	0.05	500
0.50	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

* 2% stock solution provides 10 mg/L dose in a 2-L jar for every 1 mL of stock solution added to the jar

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Example: 0.01% Superfloc N300 dry polyacrylamide stock solution

N300 = 99.7% by weight active polymer

Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	[illegible]	500
0.50	[illegible]	1,000
1.0	[illegible]	2,000
2.5	[illegible]	5,000
5.0	[illegible]	10,000
10.0	[illegible]	20,000

How many grams of N300 to add to make 1 liter of a 0.01% N300 stock solution?

$$C3 = \left(\frac{10{,}000\ \text{mg/l}}{1\%}\right) x\ 0.01\%$$

C3 = 0.01%

V3 = 1 Liter

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Example: 0.01% Superfloc N300 dry polyacrylamide stock solution

N300 = 99.7% by weight active polymer

Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	[illegible]	[illegible]
0.50	[illegible]	[illegible]
1.0	[illegible]	[illegible]
2.5	[illegible]	[illegible]
5.0	[illegible]	[illegible]
10.0	[illegible]	[illegible]

How many grams of N300 to add to make 1 liter of a 0.01% N300 stock solution?

$$C3 = \left(\frac{10{,}000\ \text{mg/l}}{1\%}\right) x\ 0.01\%$$

C3 = 0.01%

(100 mg/L)

V3 = 1 Liter

$C3 = \underline{100\ mg/l}$

$$100\frac{mg}{l} x\ 1\ liter = 100\ mg\ of\ \textbf{active}\ polymer$$

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Example: 0.01% Superfloc N300 dry polyacrylamide stock solution

N300 = 99.7% by weight active polymer

$\left(\frac{99.7\%}{100\%}\right)$ = 0.997 mg active polymer per 100 mg of N300

How many grams of N300 to add to make 1 liter of a 0.01% N300 stock solution?

C3 = 0.01%

(100 mg/L)

V3 = 1 Liter

Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100

$C3 = \underline{100\ mg/l}$

$$100\frac{mg}{l} x\ 1\ liter = 100\ mg\ of\ \textbf{active}\ polymer$$

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Example: 0.01% Superfloc N300 dry polyacrylamide stock solution

N300 = 99.7% by weight active polymer

$\left(\frac{99.7\%}{100\%}\right)$ = 0.997 mg active polymer per 100 mg of N300

$$100.3\ mg\ N300 = \left(\frac{100\ mg\ active\ polymer\ needed\ in\ flask}{0.997}\right)$$

How many grams of N300 to add to make 1 liter of a 0.01% N300 stock solution?

C3 = 0.01%

(100 mg/L)

V3 = 1 Liter

Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100

$C3 = \underline{100\ mg/l}$

$$100\frac{mg}{l} x\ 1\ liter = 100\ mg\ of\ \textbf{active}\ polymer$$

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Example: 0.01% Superfloc N300 polymer stock solution

0.01% Polymer Stock Solution *

1 mL → 2-L Jar 1 → 0.10 mg/L

2 mL → 2-L Jar 2 → 0.20 mg/L

Dose

Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100

* 0.01% stock solution provides 0.10 mg/L dose in a 2-L jar for every 1 mL of stock solution added to the jar

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Make a stock solution reference table

Dose in mg/L for each mL of Stock Solution Added to a 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	0.05	500
0.50	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

Example: For every 1 mL of a 2% stock solution (20,000 mg/l) added to a 2-L jar, the coagulant concentration in the jar increases by 10 mg/l (add 2 ml for 20 mg/l, 3 ml for 30 mg/l, etc.)

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Make a procedure & reference table for stock solutions

The goal of this guideline is to help you "Prepare a Stock Solution"

Table 1: Determining the concentration of the stock solutions

To use Table 1, FIRST determine how much raw water you will be adding to each jar. For example, if you are using 2,000 mL jars and conducting a conventional jar test, you will typically be adding 2,000 mL to each jar. SECOND, consider the chemical dosages that are to be added to each jar. For example, you may want the alum dosage to increase by 10 mg/L in each jar. THIRD, identify the stock solution concentration (%) that you need to prepare and transfer this information to **Table 3** below.

Table 1		
How much raw water are you going to put in each jar?	2000	mL
How much do you want the dosage (mg/L) to change for each milliliter (mL) of stock solution that you add to a jar?	Concentration of the stock solution that you need to prepare (%)	(Mg/L)
0.05	0.01	100
0.25	0.05	500
0.50	0.1	1000
1.00	0.2	2000
2.50	0.5	5000
5.00	1.0	10000
10.00	2.0	20000
15.00	3.0	30000
20.00	4.0	40000
	0.00	0

Return to Data Entry Screen

The following equation is used to calculate the Stock Solution Concentration in Table 1:

Stock Solution Concentration (%) =

$$\frac{\text{Desired Dosage (mg/L)} \times \text{Volume of Raw Water (mL)}}{\text{Amount of Stock Solution added to each jar (1 mL)} \times 10{,}000 \text{ (mg/L to \% conversion factor)}}$$

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Make a form or spreadsheet

Table 2: Determining the product strength of liquid chemicals

To determine how much liquid chemical you must use to prepare the stock solution, you must first determine the product strength. Product strength is the actual (reactive) chemical that is contained in each gallon of liquid. To determine the product strength, you must know the product specific gravity and percent concentration. For example, liquid alum has a product specific gravity of 1.35 and a percent concentration of about 48 %. Product specific gravity and percent concentration can be determined from the product supplier and product information sources such as MSDS. Once the product specific gravity and percent concentration are known, Table 2 can be used to determine the product strength.

Table 2			
Coag/Chemical =>	Alum	Mangafloc LT20	Superfloc N-300
Product Strength (%)	48.5%	100.0%	99.7%
Specific Gravity	1.35	0.80	0.75
Product Strength (lb/gal)	5.46	6.67	6.24

Table 3: Making the stock solution

Table 3			
Step 1 - Select desired stock solution concentration from Table 1 above			
Desired Stock	Alum	Mangafloc LT20	Superfloc N-300
Solution Concentration (%)	2	0.1	0.01
Step 2 - Determine amount of product to add to flask of indicated size			
If product is a DRY			
Parameter	Alum	Mangafloc LT20	Superfloc N-300
Flask size (mL)		1,000	1000
Product Purity, %		100	99.7
Weight to add to flask, gm	0.000	1.000	0.100
If product is LIQUID			
Parameter	Alum	Mangafloc LT20	Superfloc N-300
Flask size (mL)	1,000		
Product Strength, lb/gal	5.46		
Volume to add to flask, mL	30.549	0.000	0.000

The following equation is used to determine the product volume:

$$\text{Product volume (mL)} = \frac{\text{(\% solution)} \times \text{(flask volume, mL)} \times \text{(8.34 lb/gal)}}{100 \times \text{(product strength, lb/gal)}}$$

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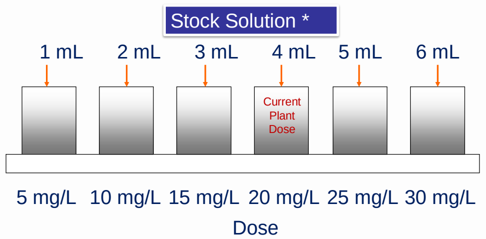
Example Jar Test Setup



* 1% stock solution provides 5 mg/L dose in 2 L jar per 1 mL added

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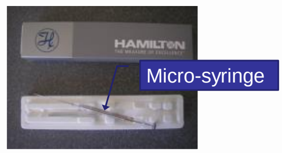
Adding Coagulant Directly to Jars Using Micro-syringe

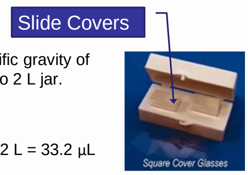
- Some vendors (e.g. DelPac) recommend dosing their coagulant using micro-syringes (versus making a stock solution).
- Coagulant is placed on septum or slide cover and dropped into the jars.



For example:

- DelPac product with specific gravity of 1.206 and 20 mg/L dose to 2 L jar.
- Required volume:

20 mg/L x (1 µl/1.206 mg) x 2 L = 33.2 µL



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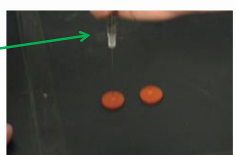
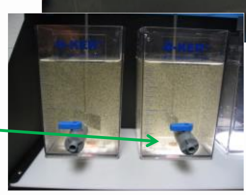
Adding Coagulant Directly to Jars Using Micro-syringe

- Deliver coagulant to septa or slide cover using micro-syringe.
- Drop the septa into the jar at the time when coagulant is to be added.
- Septa stays in jar during the test but can be retrieved, washed, and re-used.





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Equipment and Technique Considerations

- Thoroughly clean jars and mixers to remove chemical residue.
- 2-liter square jars preferred with sample tap at 10 cm:
  - 2-liter beakers acceptable (with baffles)
- Transferring dose:
  - Multiple syringes (1cc = 1mL)
  - Containers with pre-measured volumes (rinse container with distilled water after transfer)
  - Use microsyringe and septa if dosing neat.
- Sampling:
  - Flush sample taps slowly before sampling (displace tube volume).

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Initial Jar Test Settings

- Based on existing unit process sizes and equipment mixing energy
- Based on current plant flows and basin loadings
- Use as a starting point for making a jar test work at your plant
- Initial settings should be calibrated

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Exercise – Jar Test Demonstration

- Use 4-jar mixer
- Use one 2-L square jar and three 1-L round jars
- Make 1% Alum Stock Solution
- Dose Jars

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Calibration of Jar Test Settings

- Main criticism of jar testing:

  Jar test results do not predict my plant's performance.
- Possible reasons:
  - Inaccurate dosing of jars
  - Stock solutions are not accurate
  - Water temperature effects
  - Jar testing equipment is not clean (residual chemicals)
  - Out-of-date or damaged jar testing equipment
  - Jar conditions do not match plant conditions (i.e., mixing energy, detention time, sludge addition)
  - Plant conditions are not what they are assumed to be (e.g., inaccurate dosing, plugged chemical feed lines, short-circuiting, mixing energy too low or too high)

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What is Jar Test Calibration?

- Jar test calibration is the systematic use of special studies to match plant and jar test conditions so that jar testing can be used as a useful tool to support plant optimization!
- Requires a commitment at the staff level to "make the jar test work"

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Jar Test Calibration is Conducted in Four Studies

- Study 1 – Quality Control
- Study 2 – Rapid Mix
- Study 3 – Flocculation
- Study 4 – Sedimentation

Studies will likely need to be repeated to complete the jar test calibration for your plant!!

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Equipment Needed

- Jar Tester (6 jars, 300-rpm)
- Six 2-L Square Jars
- Portable or benchtop turbidimeter
- pH analyzer
- Misc. lab ware for making stock solution

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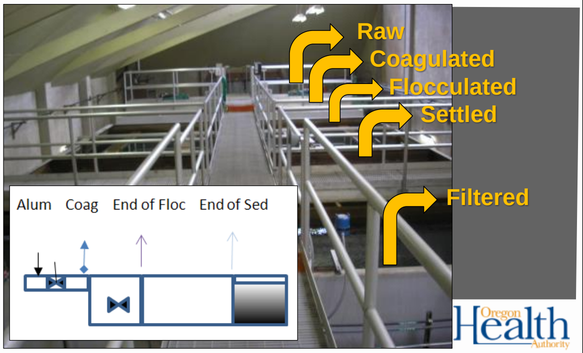
Sampling Sites - Lab

Raw water sample line – clearly labeled taps help!

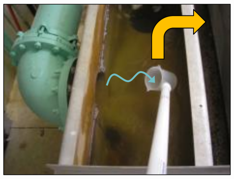
Sampling Sites - Plant



Sampling Sites - Plant

Raw
(pre alum addition)

Coagulated
(post rapid mix)

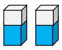


Study 1 - Quality Control

- This special study must be successfully accomplished before proceeding with jar test calibration at your facility.
- Settling curves are used as a primary indicator during jar test calibration to show that similar floc is being formed in the jar as well as in the plant.
- Approach: Treat two jars in an identical manner. Develop settling curves for both jars.

Study 1 – Quality Control (checking sampling technique)

- Use 2 jars filled with raw water



- Dose both jars equally with the current plant dose
- Place in jar tester and complete jar test sequence for your plant

Time min	Jar 1 NTU	Jar 2 NTU
0	5.14	5.75
1	5.55	5.99
2	5.33	5.3
4	5.03	4.48
6	4.44	5.06
8	4.42	4.35
10	3.67	3.87

Example Jar Speed	Example Mix Time
300 RPM	5 seconds
77 RPM	30 seconds
52 RPM	20 minutes
Turn mixer off and wait 1 minute for jars to stop spinning (the end of this wait period will be considered T = 0 minutes for sampling)	
Settle for 10 minutes, sampling turbidity from each jar at T = 0, 1, 2, 4, 6, 8, and 10 minutes.	

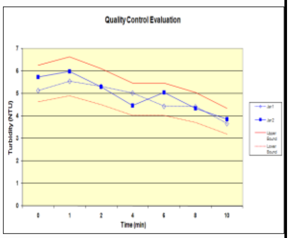
Data will be tabulated and graphed (1 curve for each jar)
If curves match – quality control is good

Study 1 – Compare the Two Settling Curves

Time min	Jar 1 NTU	Jar 2 NTU	Absolute Difference (Diff between Jar 1 and Jar 2) NTU
0	5.14	5.75	0.61
1	5.55	5.99	0.44
2	5.33	5.3	0.03
4	5.03	4.48	0.55
6	4.44	5.06	0.62
8	4.42	4.35	0.07
10	3.67	3.87	0.2
Total ABS difference:			2.52 NTU
Average of all readings			4.88 NTU
Ratio: Total ABS diff ÷ Avg of all readings:			0.52

Ratio ≤ 1.0 indicates lines considered to be similar
2.0 ≥ Ratio > 1.0 indicates room for improvement
Ratio > 2.0 indicates dissimilar lines

If reproducible results are not achieved, technique must be addressed… repeat the study!



How is quality control study useful?

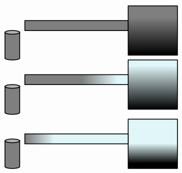
Study 1 – Quality Control Special Study

- Helps refine sampling technique
- Not flushing sampling line leads to erroneous results

T = 0 min: 2 NTU

T = 5 min: 2 NTU

T = 10 min: 2 NTU



2 NTU

1 NTU

0.5 NTU

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Study 2 – Rapid Mix Process Calibration

- Calibration factors (variables):
  - Detention time & mixing energy – Start with theoretical for your plant
  - Definition of rapid mix is often expanded to include multiple mixing zones.
  - Chemical addition – Match chemical addition in plant. Use sample location with the most chemicals added.
- Performance indicators:
  - Measure pH following rapid mix in jars and compare to pH following plant rapid mix (works best with alum and ferric).
  - Matched pH indicates accurate stock solutions and jar test dosing.

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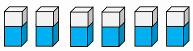
Study 2 – Rapid Mix (For alum, match pH to verify dose & stock solution)

- Use 6 jars filled with raw water



- Dose jars to bracket current plant dose (jar 1 to have no coagulant, jar 4 to have plant dose)
- Place in jar tester and complete the following mixing/sampling sequence:

Jar	Dose Mg/l	Jar pH	Plant Grab Sample pH
1	0 (blank)	7.1	
2	10	6.7	
3	12	6.6	
4	16 (plant dose)	6.4	6.3
5	20	6.1	
6	20	6.1	

Example Jar Speed	Example Mix Time
300 RPM	5 seconds
77 RPM	30 seconds
10 RPM	While sampling
Sample pH from each jar	
Sample pH of coagulated water from the plant (grab sample just prior to flocculation)	

Data will be tabulated and graphed (1 curve for each

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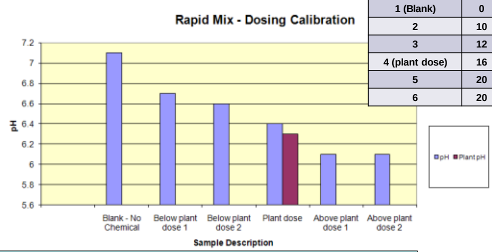
Study 2 – Rapid Mix Results

Jar	Dose mg/l	Jar pH	Plant pH
1 (Blank)	0	7.1	
2	10	6.7	
3	12	6.6	
4 (plant dose)	16	6.4	6.3
5	20	6.1	
6	20	6.1	



Interpretation of Results:
Some coagulants like alum will lower the pH. The pH in the jar at the plant dose should match the plant pH. If not, then check dosage calculations and/or stock solution preparation.

Note: the rapid mix setting (time and jar mixing speed) is not confirmed by this study.

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How is rapid mix study useful?

Study 2 – Rapid Mix/Dosing Control Special Study

- If you are not able to replicate plant dose in the jar, the reverse may also be true – i.e., you may want to replicate results of different coagulant doses you've created in the jars.
- Procedures for making stock solutions may need refining.
- Plant dose calculations may need to be revised.
- Coagulant pump output may not be as predicted, as evidenced by a pump calibration.

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Study 3 – Flocculation Process Calibration

- Calibration factors:
  - Detention time – Start with theoretical for each stage.
  - Chemical addition – If feeding flocculent aid, match dose and feed location.
  - Mixing energy – Start with theoretical mixing energy for each stage
- Performance indicators:
  - Floc particle settling characteristics
  - Compare jar and plant settling curves following flocculation

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Study 3 – Flocculation Process Calibration

- Calibration Steps:
  - 1st – collect coagulated water from the beginning of the floc basin in a jar, being careful not to break floc apart.
  - Take the jar of coagulated water and then run the jar test procedure beginning with the flocculation stage (e.g., slow mixing @ 30-40 rpm for example). After 20 minutes of mixing, stop the mixer and beginning sampling turbidity to develop a settling curve, similar to what was done in Study 1.
  - Take another jar of coagulated water from the end of the floc basin, by carefully dipping into the basin. Then, without further mixing, develop a settling curve for this sample similar to what was done in Study 1.
  - Graph and compare both settling curves.

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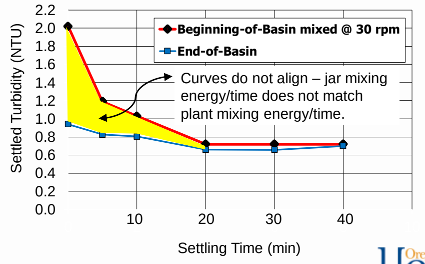
Study 3 – Compare Settling Curves from Beginning-of-Floc-Basin and End-of-Floc-Basin Sampling.



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Flocculation – Studies 3b and 3c (Adjust mixing time and speed – observe impact)

- **Study 3b – ½ mixing time (same speed)**
  - Use 2 jars
  - Repeat study 3a with only ½ the mixing time
  - Tabulate and plot the results to see the impact
- **Study 3c – ½ mixing speed (same time)**
  - Use 2 jars
  - Repeat study 3a with only ½ the mixing speed
  - Tabulate and plot the results to see the impact

3b. Results for ½ Time

Time min	Jar 1 NTU	Jar 2 NTU
0	1.79	1.87
1	2.01	1.83
2	2.02	1.87
4	1.8	1.95
6	1.83	1.86
8	1.87	1.76
10	1.85	1.86

3c. Results for ½ Speed

Time min	Jar 1 NTU	Jar 2 NTU
0	1.72	2.14
1	1.64	2.21
2	1.65	1.96
4	1.63	2.09
6	1.72	2
8	1.39	1.98
10	1.16	1.96

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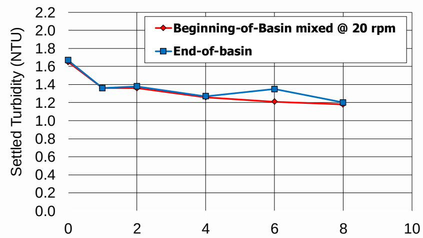
Study 3 – Example Showing Impact on Settling Curve When Jar Mixing Energy Decreased



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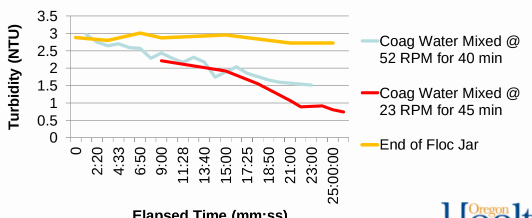
How is flocculation study useful?

- Study 3 – Flocculation Process Calibration

  You may want to replicate different flocculation speeds in your jars (think of the jars as a pilot plant) before trying the change full-scale.



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Study 4 – Sedimentation Process Calibration

- Calibration approach for sedimentation:
  - A theoretical jar sampling time can be calculated by knowing the sedimentation basin loading rate.
    - For example: surface loading rate = 0.5 gpm/ft^2 ~ **2 cm/min**
    - Sampling jar after 5 minutes is equivalent to this loading rate (10 cm settling distance ÷ **2 cm/min**)
    - Add extra time for the water in the jars to stop moving after mixer is stopped (e.g., ½ to 1 minute; maybe settle for 6 min.)
  - Sedimentation calibration is conducted by collecting 2 jars of water from the end of the flocculation basin, prior to settling, simulating a slow mix step in the jar tester, and developing a settling curve over ~ 30 minutes.

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Study 4 – Enhancement to Sedimentation Process Calibration

- Impacts of continued flocculation in sedimentation basin:
  - Continued flocculation typically occurs at the beginning of conventional sedimentation basins.
  - The result is larger, faster settling particles, and plant performance is often better than jar performance.
- To simulate this effect, a short period of time and low energy are applied to the end of floc basin sample to start the test (e.g., 5 minutes @ 7 rpm).

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Study 4 – Sedimentation Process Calibration

- Fill 2 jars from end of flocculation process. Two jars are used to minimize drawdown in the jars during sampling.
- Start the test with the slow mix step (e.g., 5 min. @ 10 rpm to keep floc suspended).
- Next, sample jars alternately from Time 0 to ~ 30 minutes.
- While conducting the settling test, also collect samples of the sedimentation basin effluent and measure turbidity.
- Compare jar settling curves with actual sedimentation basin performance.

Time	Jar 1	Jar 2
0	Sample	
2		Sample
4	Sample	
6		Sample
8	Sample	
Continue alternating to ~ 30 min.		

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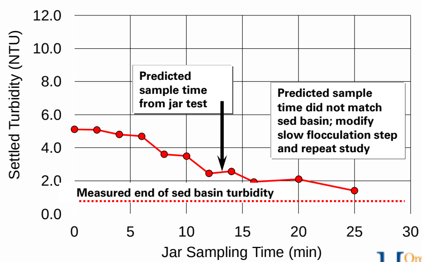
Study 4 – Example Settling Curve to Assess Sedimentation Sampling Time



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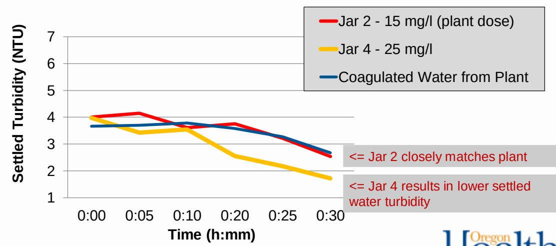
How is sedimentation study useful?

- Study 4 – Sedimentation Process Calibration

This may influence a decision to switch coagulants or dosages.



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Example Calibrated Jar Test Settings

- Rapid Mix:
  - Set jar mixer to 300 rpm (static mixer).
  - Add Alum coagulant and mix @ 300 rpm for 5 seconds.
  - Turn down mixer to 77 rpm for 2 minutes (pipeline mixing).
- Flocculation:
  - Turn down mixer to 40 rpm for 15 minutes (1st stage floc).
  - Turn down mixer to 25 rpm for 15 minutes (2nd stage floc).
  - Turn down mixer to 7 rpm for 10 minutes (floc/sed transition mixing).
- Sedimentation:
  - Stop mixer.
  - Sample jars for turbidity after 10 minutes.

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During the Jar Test Calibration Process…

- You may discover things about your plant that you did not know before.
- Initial special studies may point to plant limitations:
  - Flow splitting
  - Chemical feeding
  - Limited range in mixing energy (i.e., rapid mix, flocculation)
  - Others
- Identifying and correcting plant limitations is part of jar test calibration and future special studies.
- Remember "special studies breed more special studies."

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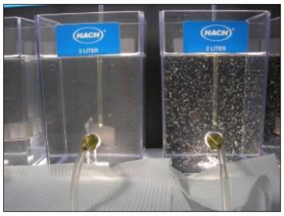
Summary

- Gain experience and confidence with jar testing – it can be a powerful tool.
- Paying attention to details makes the difference between a good jar test and a bad one.



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Streaming Current

Streaming current

1. A device consisting of a piston within a cylinder that is used to draw the water sample in, induce a current through fluid motion, and measures the streaming current as a constant signal output.
2. A stationary liquid boundary layer lies at the surface of both a piston and a cylinder, which contains negatively charged particles. Since the stationary layers contain negative particles, the fluid between the cylinder wall and the piston becomes positively charged. These two oppositely charged layers glide past each other as the piston moves up and down in the cylinder. This movement of two charged layers, induces a current, which is then measured by an electrode in microamperes.
3. The current is an alternating current (AC) due to the back and forth motion of the piston. This alternating current is then rectified and time-smoothed to provide a "streaming current" or constant signal output (numerical reading).

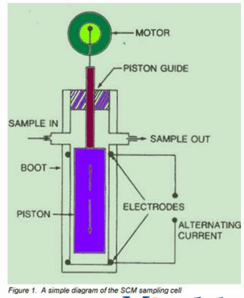

Figure 1. A simple diagram of the SCM sampling cell

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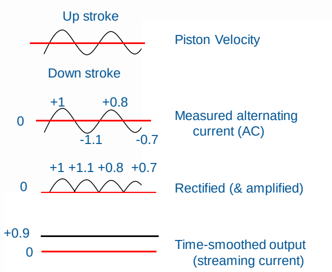
Streaming Current

Output ("zero offset out") is in relative units (does not provide actual current or charge density due to sensitivity in small differences between the cylinder wall).

Measured current is impacted by irregularities in the cylinder wall as well as the motor speed.

Span/gain adjustment:
Used to vary output by a factor of up to 30 or 50. 10% dose change = +10

Zero adjust/"Zero offset in":
Used to move the reading up or down in value by a selected amount.



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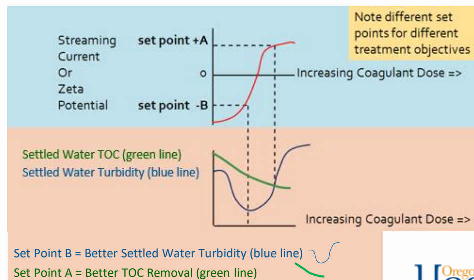
Streaming Current - Particle Charge Relationship to Turbidity & TOC

An example of how particle charge can be related to settled water turbidity and TOC removal.



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Streaming Current Response

- Streaming current goes more positive caused by:
  - Decrease in: pH, flow, color, turbidity, lime, caustic, and anionic polymers
  - Increase in: Alum, Ferric sulfate, ferrous sulfate, PAC, cationic polymers, and chlorine.
- Potassium permanganate has no appreciable effect (1-2 ppm dose)
- "Set point" determined by optimizing coagulation and turbidity/TOC removal (jar testing) and noting SC reading

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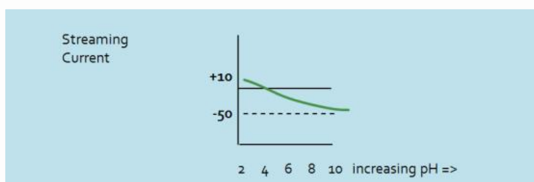
Streaming Current - Particle Charge Relationship to pH

An example of how particle charge can be related to a buffered kaolinite suspension of varying pH.



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Streaming Current - Rapid Fluctuations

Rapid fluctuations in SCD readings can be caused by:

- Improperly mixed coagulant in the sample line causing the detector to measure alternating doses of coagulated and under-coagulated water
- Extended off and on periods of the coagulant feed system, that provides periods of under dosing and over dosing, even though the dose may be correct when averaged over time.
- SCD sensor in need of cleaning. Be sure to check sample lines as clogging is a commonly reported problem – clear sample lines help identify problems.

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Streaming Current – Good Applications

- Streaming current detectors set up to control coagulant dose are good for:
  - When charge neutralization is the main objective
  - Responding to rapid changes in raw water quality (e.g. storm events)
  - Compensating for variations in strengths of similar products or different batches of same product
  - Responding to changes in plant influent flow rates
- Periodic jar testing to verify the optimal set point is strongly recommended.

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Streaming Current – Considerations

- Control - Where the coagulant is controlled by the SCD controller, but not the lime addition for pH. The solution is to control both the pH and coagulant feed rates at a constant proportion with the ability to manually fine-tune the proportion.
- PAC - The periodic addition of PAC may require that set points be closely monitored. The PAC may add a coagulant demand due to its negative surface charge, but may also lower the coagulant demand, depending upon the level of organics adsorbed by the PAC
- Maintenance - Fe, Mn and lime can deposit and foul sensor (Clean per Mfr. Recommendations)
- Temperature - Where temperature fluctuations greatly impact coagulation rates. The solution is to determine optimum set points monthly or at least quarterly.

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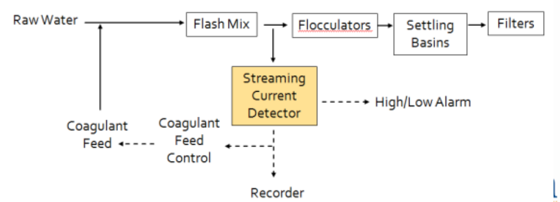
Streaming Current Device Placement

- Placement should be after coagulant addition and rapid mixing.
- Depending on the efficiency of the rapid mix, a delay time of 2-5 minutes should be incorporated (e.g. through a longer sample line) to ensure the coagulant has fully equilibrated. If the coagulant is given enough time to adsorb or precipitate onto particles, less of it will remain in solution to deposit onto surfaces of the SCD's sensor.
- On the other hand, an excessive lag time will cause an excessively delayed coagulant feed control response causing the coagulant feed control to "chase" the SCD set point.



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Streaming Current – Jar Testing

Jar testing can help identify:

- Sensor malfunction or need for cleaning
- When "sweep floc" coagulation may be needed
- Temperature effects
- Signal delay effects
- Optimum dose for removal of NOM, as indicated by TOC or UV254

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Impact of Coagulation Choices

What you do in the treatment plant can affect corrosion in the distribution system…

Parameter	Effect of Enhanced Coagulation	Lead	Copper	Iron	Lead from Brass	Concrete
TOC	↓	--	▲	↓	↓	▲
Alkalinity	↓	▲	↓	▲	▲	▲
Aluminum	▲	▲	▲	?	?	▲
pH	↓	▲	▲	▲	▲	▲
Sulfate	▲	↓	▲	▲	↓	--
Chlorite	▲	▲	↓	▲	▲	--

▲ Increase (bad) ↓ Decrease (good) -- Same (no change) ? Impact Unknown

Adapted from table on pg 6-13 of the *Enhanced Coagulation & Enhanced Precipitative Softening Guidance Manual*. USEPA. 1999.

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Exercise

- Form groups of 4 or 5 and…
  1. Share your process for coagulation control with your group.
  2. Share at least 1 experience that helped you better improve your process.
  3. Identify any opportunities to improve your process.
- Identify one person to report to the class:
  1. What was the most common coagulation control tool or method used?
  2. Report on at least 1 experience that the class may be able to benefit from.
  3. Provide an example of at least 1 opportunity for improvement identified among your group.

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Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

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