Coagulation/Flocculation Workshop

Course # 3103

Updated June 2020

Fleming Training Center

State of Tennessee

Coagulation / Flocculation Workshop

June 23 - 25, 2020

Course #3103

Tuesday

8:30	Registration and Welcome	Amanda Carter
8:45	Water Clarification Training	Amanda
11:45	Lunch	
1:00	Jar Testing Math	Amanda

Wednesday

8:30	Plant Example	Amanda
11:45	Lunch	
1:00	Laboratory	Amanda

Thursday

8:30	Laboratory	Amanda
9:45	Exam Review	Amanda
11:15	Lunch	
12:30	Course Review and Exam	Amanda

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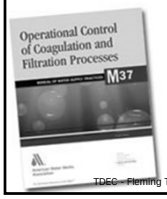
Table of Contents

Section 1	Coagulation and Flocculation	3
Section 2	Math	21
Section 3	Plant Examples	67
Section 4	Laboratory	79

Section 1

Coagulation / Flocculation

Coagulation/Flocculation Workshop



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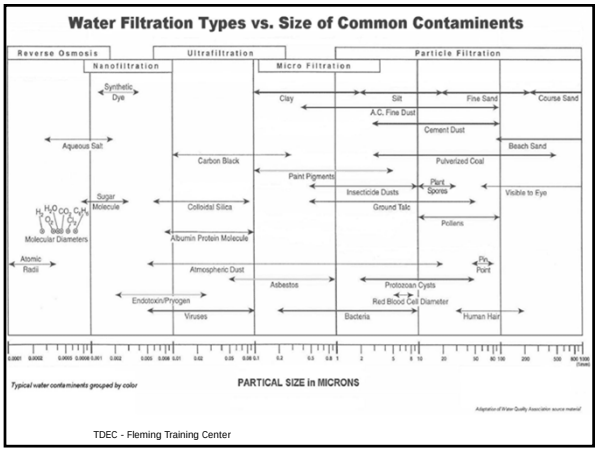
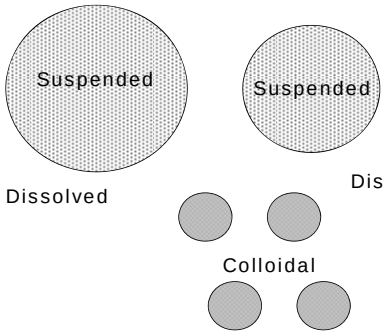
Objectives of Water Treatment

- One objective of water treatment professionals is to manage the removal of solids in the water that make it unsuitable for drinking.
- These solids can be either particulate, dissolved or colloidal in size and character.





Particle Diameter, mm	Representative Particle	Time Required to Settle 1 foot
10	Gravel	0.3 sec
1	Coarse sand	3 sec
0.1	Fine sand	38 sec
0.01	Silt	33 min
0.001	Bacteria	55 hours
0.0001	Color	230 days
0.00001	Colloidal particles	6.3 yrs
0.000001	Colloidal Particles	63 year min

Suspended Solid

- A solid organic or inorganic particle that is held in suspension by the action of flowing water.

Suspended Solids Common In Surface Waters

- Clay
- Sand
- Silt
- Bacteria
- Algae and other microorganisms

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Suspended Solids Common In Surface Waters

- Effects of Particulates
  - Turbidity
  - Suspended solids
  - Taste and odors
  - Corrosion

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Colloidal Solid

- Finely divided solid that will not settle out of water for very long periods of time unless the coagulation-flocculation process is used.

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Colloidal Solids Common In Surface Waters

- Water color
- Aquatic humic substances
- Decomposition by-products (organic)
- Industrial wastes
- Silica
- Calcium carbonate

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Colloidal Solids Common In Surface Waters

- Effects of colloidal material
  - Turbidity
  - Deposition
  - Taste and odors
  - Increase coagulant usage and residuals
  - Disinfection by-products (THM's)

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Dissolved Solid

- Any material that is dissolved in water and can be recovered by evaporating the water after filtering out the suspended material.

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Dissolved Solids Common In Surface and Ground Waters

- Water hardness
  - Calcium
  - Magnesium
- Iron and manganese
- Heavy metals
- Nitrates and nitrites
- Salts
  - Chlorides
  - Sulfates
  - Sulfides
- Fluoride and silica compounds

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Dissolved Solids Common In Surface and Ground Waters

- Effects of dissolved solids
  - Scaling and deposits
  - Tastes and odors
  - Toxic effects
  - Corrosion
  - Staining

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Colloidal and Suspended Particles

- These particles have a surface charge which is responsible for their “stability” to remain separate and suspended in the water.

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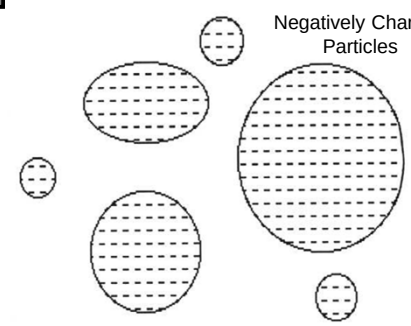

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Coagulation

- The water treatment process that causes very small suspended particles to attract one another and form larger particles
- This is accomplished by the addition of a chemical, called a coagulant, that neutralizes the electrostatic charges on the particles that cause them to repel each other

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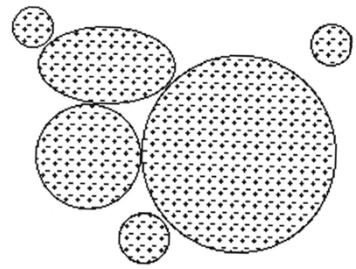

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Initial Mixing

- Purpose is to completely mix the coagulant into the raw water flow stream in a fast and uniform manner
- Hydrolysis takes place almost instantaneously during the addition of the coagulant
  - Less than 1 second
- Complete floc development may take several minutes

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Initial Mixing cont.

- Flash mix and rapid mix can be used interchangeably
- When conducting a jar test, the time the mixer runs at rapid mix should be equivalent to the effective detention time of the flash mix chamber in the plant

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Flocculation

- The water treatment process, following coagulation, that uses gentle stirring to bring suspended particles together so that they will form larger, more settleable clumps called floc.

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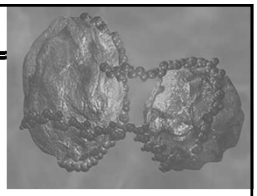

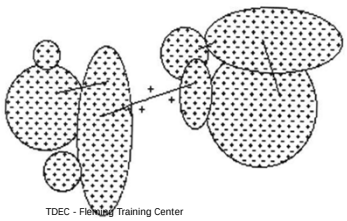

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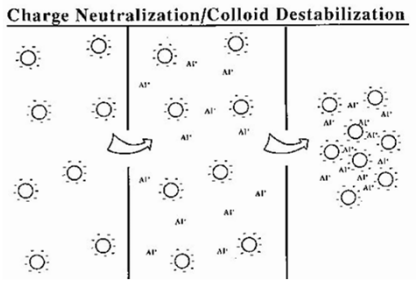

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Floc Characteristics

- A typical conventional surface water treatment plant process that uses sedimentation followed by filtration benefits from a large, heavy floc that helps settling

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Floc Characteristics cont.

- A common misconception is that increasing the chemical dose increases the settling efficiency of the floc particles because the larger floc looks great in the basins
  - This larger floc particle is more often just a chemical floc, such as aluminum hydroxide precipitate
  - In reality, this dose increase is a waste of chemicals and therefore money and it creates more sludge to waste

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Common Coagulants

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Coagulants

- Coagulants - positively charged chemicals that neutralize negatively charged particles in water to promote coagulation
  - Alum (aluminum sulfate)
  - Ferric Sulfate / Ferric Chloride
  - Organic Polymers
  - Polyaluminum chlorides

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Alum

- Advantages
  - Inexpensive
  - Handles variable water
  - Historically used coagulant
  - Broad application window
  - Effective at organic removal

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Alum

- Disadvantages
  - Produces large amounts of chemical solids
  - Reduction in alkalinity
  - Poor cold water performance
  - Potential post precipitation problems

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Ferric Sulfate/Ferric Chloride

- Advantages
  - Inexpensive
  - Applied over a broad pH range
  - Effective at organic removal
  - Large floc formation

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Ferric Sulfate/Ferric Chloride

- Disadvantages
  - Potential colored water
  - Highly staining chemical
  - Very corrosive products that can increase maintenance costs
  - Large chemical solids formation
  - Strong alkalinity reduction
  - Heavy metal considerations

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Organic Polymers

- Advantages
  - Low dosages applied
  - Minimal chemical solids generation
  - No alkalinity reduction
  - Aids in dewatering of sludge
  - Reaction independent of pH and alkalinity
  - Good cold water performance

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Organic Polymers

- Disadvantages
  - Expensive
  - Must base product choice on performance
  - Poor primary coagulants
  - Potential filter fouling
  - Can adversely effect filter run lengths
  - Possible monomer residuals

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Polyaluminum Chloride Products

- Other chemical names
  - Aluminum Chlorohydrate (ACH)
  - Aluminum Hydroxychloride
  - Aluminum Chloride Hydroxide
  - Polyaluminum Chloride
  - Polyaluminumchlorosulfate

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Polyaluminum Chloride Products

- Theoretical chemical formulae
  - $Al_2(OH)_{6-x}\ Cl_x$
    - PACl or Polyaluminum Chloride
  - $Al_2(OH)_{(6-(x+2z))}\ Cl_x(SO_4)_z$
    - PACS or Polyaluminum Chlorosulfate
  - $Al_2(OH)_{(6-2z)}(SO_4)_z$
    - PAS or Polyaluminum Sulfate

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Polyaluminum Chloride Products

- <u>Basicity</u> - The theoretical number of hydroxyl groups associated with the aluminum metals.
  - Basicity (%) = $[OH^-]/3[Al^{+3}] \times 100$

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Polyaluminum Chloride Products

- Basicity (%) = $[OH^-]/3[Al^{+3}] \times 100$
  - Low Basicity = 0-33%
    - $Al_2(OH)_{6-x}Cl_x$ x = 4 to 6
  - Middle Basicity = 34 - 67%
    - $Al_2(OH)_{6-x}Cl_x$ x= 2 to 3.99
  - High Basicity = 68- 83%
    - $Al_2(OH)_{6-x}Cl_x$ x < 2

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PACl Products – Basicity Related to Performance

- Low
  - More like $AlCl_3$
  - Competes with traditional coagulants
  - Faster reaction
  - More pH depression
  - More corrosive
  - Good TOC removal
- High
  - More like polymers
  - Multiple applications
  - Less chemical solids generated
  - Less pH depression
  - Less alkalinity consumption

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Polyaluminum Chloride Products

- Advantages
  - Variety of products that can meet multiple goals
  - Improve overall water quality versus traditional coagulants
  - Better plant operations
  - ACH is highly concentrated aluminum source
  - Overall treatment cost savings

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Polyaluminum Chloride Products

- Disadvantages
  - Must base product choice on performance
  - Relative $/# is higher than traditional salts
  - Overall cost picture must be calculated
  - Must be applied properly
  - Most plants don't have historical data with PACl
  - Should match flocculant to PACl

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PACl Product Comparisons – TOC Removal

Coagulant	TOC Removal		
	(%)	Dose	Active Metal Dose
Low Basicity PACl	38.4	0.03	1.14
Mid Basicity PACl	30.0	0.03	0.88
High Basicity PACl/ACH	26.5	0.10	0.94
PACS (Polyaluminum Chlorosulfate)	28.1	0.04	0.82

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PACl Product Comparisons – Particulate Removal

Size Range	Removal by High Basicity PACl	Removal by Mid Basicity PACS
< 2 mm	67%	60%
2-5 mm	57%	45%
5-10 mm	60%	33%

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PACl Product Comparisons

- Equal Metal Application Dosages

	Applied Dose
PACl 5.3% as Al or 10% Al_2O_3	30 mg/L
10 - 70% Basicity	
ACH 12.7% as Al or 24% Al_2O_3	12.5 mg/L
83% Basicity	

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Coagulant Blends

- Inorganic salt w/ organic polymers
  - Various ratios
- Inorganic w/ acid
  - Various ratios
- Inorganic w/ additive

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Various Coagulant Applications

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Various Coagulant Applications

- Reduced particle counts
- Ease of use
- Cost savings
- Chemical residue (sludge) reduction
- Aluminum residual reduction
- Stable treated water
- Longer filter runs
- Cold water treatment
- TOC, THM, HAA removal
- Faster settling rates

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Various Coagulant Applications

- Set/prioritize treatment goals
- Understand individual raw water issues
  - Cold water
  - Low alkalinity
  - High organic episodes
  - Extremely variable turbidity water
  - Highly colored water
  - Easy to treat, constant water

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Selecting the Correct Polymer

- Each polymer has a specific function
- Each type of polymer has benefits and limitations
- Understand it's limitations

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Water Soluble Solution Cationic Polymers

- Polymer reacts with the colloidal material in the water by neutralizing the charge or by bridging (tying together) individual particles to form visible insoluble floc
- Polymer has a positive charge and the colloidal material has a negative charge

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Define the Polymer Primary Treatment Goals

- Solids removal
- Settled turbidity
- Filtered turbidity
- Sludge reduction
- Filter run lengths
- Color removal

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Understanding the Water Source

- Type of source
  - Well, Lake, River
- Parameters
  - Temperature
  - Turbidity
  - pH
  - Alkalinity

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Characteristics of Organic Polymers

- Cationic polymers
  - Examples
    - Polyamines
    - Polyquaternaries
    - Polydadmac
    - Epi-dma
  - Molecular weight below 100,000
  - Available as aqueous solutions

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Characteristics of Organic Polymers

- Cationic flocculants
  - Examples
    - Copolymers of acrylamide and DMAEM/DADMAC
    - Mannich amines
  - Molecular weight over 1,000,000
  - Available as powders and emulsions

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Characteristics of Organic Polymers

- Nonionic flocculants
  - Examples
    - Polyacrylamides
  - Molecular weight over 1,000,000
  - Available as powders and emulsions

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Characteristics of Organic Polymers

- Anionic flocculants
  - Examples
    - Polyacrylates
    - Copolymers
    - Acrylamide/ acrylate
  - Molecular weight over 1,000,000
  - Available as powders and emulsions

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How to Run a Successful Plant Trial

- Define primary goals
- Understanding water source
- Chemical programs
- Design a chemical program
- Jar testing
- Plant trial

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Defining Primary Treatment Goals

- Solids removals
- Settled turbidity
- Filtered turbidity
- Color removal
- TOC/HAA removal
- Lengths of filtered runs
- Sludge reduction

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Chemical Program

- Each chemical used in a water plant influences and/or impacts the performance of another
- Understand its purpose and its limitations
- Design chemical program to:
  - Water Source
  - Applications
  - Goals

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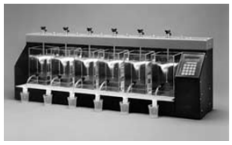
Jar Testing



- Used to screen different technologies
- Test procedure should correlate to plant's performance
  - Mixing energy
  - Slow mixing
  - Settling time

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Jar Testing

- Compare to plant's chemical program:
  - Settled turbidity
  - Filtered turbidity
  - pH
  - Alkalinity
  - Filtered Index
  - TOC/UV

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Planning and Scheduling

- Note: Valid trials are an exercise in experimental design.
- Plan carefully
- Set clear goals
- Scheduling
- Training
- Polymer/coagulant introduction

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Planning and Scheduling cont.

- Equipment
- Technical support
- Measurements made

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Planning and Scheduling cont.

- Schedule the plant trial to avoid plant projects focus on trial
- Make the trial long enough 30 to 60 days
- First week for transition period
- Second week allows for dosage optimization and operators to become familiar with the programs strengths and weaknesses

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Planning and Scheduling cont.

- Data collected after this break in period provides a valid comparison to historical data

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Product Changeover

- Use a conservative approach
- Gradual introduction of new chemistry
- Gradual weaning off of old chemistry
  - 75/25% - 50/50% - 25/75% - 100%
- Use conservative dosage
  - Optimize later
- Adjust other chemistries systematically

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Operator Training

- The fate of any trial rests in the hands of the operators
- Operators should know the trial goals, understand the new chemistry, and what to expect

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Laboratory Testing Techniques

Equipment
Solution preparation
Test procedures

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Equipment

- Jars
  - Square
  - Round
- Stirrer
- Water bath
- Analytical Equipment
  - Turbidimeter
  - pH meter
  - Thermometer

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Types of Jars

- 1-Liter Circular
  - First used
  - Least expensive
- 2-Liter Circular
- 2-Liter Square

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1-Liter Circular Jars

- Disadvantages:
  - Holds very little water
    - Minor errors in chemical doses result in large error in actual doses
  - Water rotates with paddles
    - Reduces the amount of actual mixing
  - Limited amount of water for analysis
  - Does not provide a good sampling point

In general, 1-L jars are not acceptable

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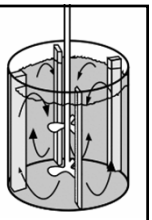
2-Liter Circular Jars



- Provides enough sample
- Stators inserted may help with mixing
  - May interfere with dosing and sampling
- Sample siphon can be added, but with some difficulty
- Disadvantage:
  - Water still rotates with the stirrer unless stators are used

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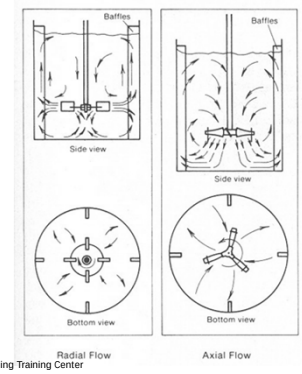

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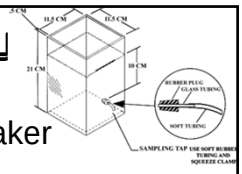
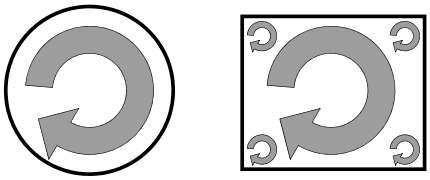
2-Liter Square Beaker



- Advantages:
  - Square configuration reduces rotation of water
  - Thicker wall and lower heat conductivity of plexiglass reduces water temp change during test
  - Jars are less fragile and can be repaired
  - Sampling port can easily be installed

Round vs. Square Mixing

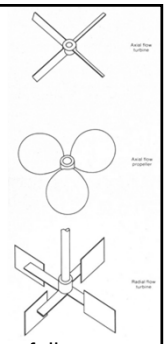


Use the same shape as your flash mix

Stirrer

- Two basic types
  - Gear-driven
    - Best
  - Magnetic-driven
    - Easier to add chemicals
    - Doesn't turn smoothly at slow speeds

Impellers



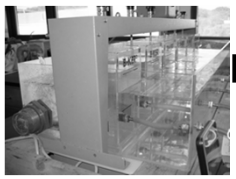
- Types
  - Paddle
  - Turbine
  - Marine
  - Axial flow
- Need the one that best simulates full scale

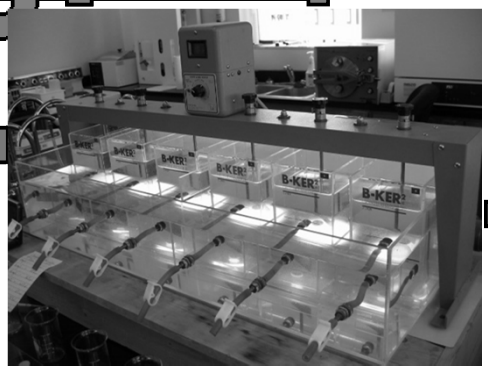
Impellers

- Magnetic stirrers are only available with paddles
  - Corresponds to paddle, walking-beam, flat-blade turbine type mixing devices
- Top mounted stirrers with flat paddles are best
  - Shaft and impeller can be changed

Water Bath

- Jars set in a rectangular tank with raw water circulating around them
- This is only necessary for cold water





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Water Bath

- Determination for use of water bath:
  - Take a raw sample
    - Run jar test immediately
  - Take another sample
    - Let warm 5-10 degrees
    - Run same test and take note in difference

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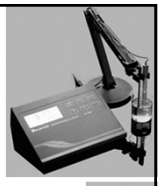
Analytical Equipment



- Turbidimeter
  - pH meter
- Thermometer
  - Pipets
- Analytical balance

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Solution Preparation

- Accuracy is critical - Small errors are compounded by large dilutions
- Dilute solutions of 1 g/L or less of coagulants or polymers should be prepared daily

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Solution Prep - Dry Products

- Dissolve 1 gram of a chemical that is 100% in 1000 mL of DI water
  - This is a 0.1% solution by weight or 1,000 mg/L
- In a 1 liter test beaker, 1 mL of the above equals 1 mg/L
- If the chemical is not 100%, then divide by the percent of the chemical available

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Solution Prep - Dry Products

- Useful dilution for alum, iron salts, carbons and alkalis
- Lower this dilution for polymers, fluorides and potassium permanganate

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Example

- How do you make a solution of chlorine containing 1000 mg/L from HTH, which has 65% available chlorine?

$$gram = \frac{1\,gram}{0.65} = 1.54\ g\ HTH\ into\ 1\ L$$

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Dry Alum

- Use a 1-L volumetric flask
- Dissolve 10 grams in 600 mL DI water
- Fill to the mark and mix
- Solution contains 10,000 mg/L
- Therefore, 1 mL of the stock solution added to a 2-L jar will equal a 5 mg/L alum dose

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Solution Prep - Liquid Products

- To make a 10 g/L solution (1% or 10,000 mg/L) of a liquid product, divide 10 gram by specific gravity
  - This is the mL of chemical to dissolve in 1000 mL DI water
  - In a 1 liter test beaker, 1 mL of the above equals 10 mg/L of liquid product
- For solutions like PACl

Remember, Jar Test beakers are usually 2 L, therefore double dose

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Solution Prep - Liquid Products

- For liquids sold on a dry basis, correct for concentration as follows

$$\frac{10\ gram}{(sp.grav)(conc.)}$$

  - In a 1 liter test beaker, 1 mL of the above equals 10 mg/L of liquid product
- For solutions like alum, ferric, sodium permanganate, etc.

Again, remember Jar Test beakers are usually 2L, therefore double dose

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Solution Prep - Liquid Products

- Example:
  - Liquid aluminum sulfate is typically sold on a dry basis.
  - 48.5% $Al_2(SO_4)_3 \bullet 14\ H_2O$ and specific gravity of 1.335

$$\frac{10\ g/L}{(1.335)(0.485)} = 15.4\ mL$$

  - 15.4 mL liquid alum into 1 L for a 10 gram/liter dry basis solution
  - 1 mL of this solution = 10 mg/L dry alum

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Solution Prep - Liquid Products

- Micropipets dispense neat product
- Specific gravity must be accounted for (liquid chemicals weigh more than water, so 1 mL of product weighs more than 1 gram)

$$\frac{mg/L}{sp.grav} = \mu L\ product\ /\ liter\ of\ test\ sol'n$$

* multiply x 2 for a 2 liter jar

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Solution Prep - Liquid Products

- For dose on a dry active product basis, divide by concentration:

$$\frac{mg/L}{(sp.grav)(conc)} = \mu L\ product/L\ test\ sol'n$$

* multiply x 2 for a 2 liter jar

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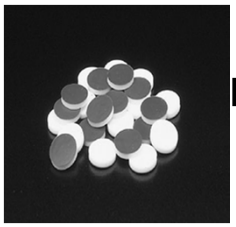
Micro-pipeting

- Try to place dose on an object that can perch on the rim of the jar until you are ready to add all at the same time
  - Septas from TOC vials
  - Powder pillows



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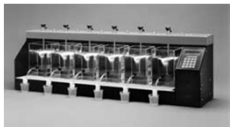
Jar Testing



- Must know volume of test jars and speed rates of stirrers prior to test
- Don't use laboratory grade chemicals
  - Use what you feed in plant

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Test Procedure

- Obtain fresh sample of water
- Sample temp. should not vary more than 3°C
- Record the following:

Temperature	pH	Turbidity
Color	Iron	Manganese
Hardness	Alkalinity	Fluoride
Phosphorus	Suspended Solids	

- Dispense equal volumes of water into jars

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Test Procedure

- Start mixing sequence and add test chemicals
- Always run a control of current program
- Mixing times and speeds are obtained from plant designs and operations
- Observe formation rate, floc size and settling rate
- Record all results

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Filterability Index

- Comparison of filtration rate of sample vs. DI water
- Helps predict the effect of a coagulant program on the filtration process
- Samples tested are clarified settled water, filter influent and jar test decants

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F-I Equipment

- Membrane filter holder 47mm
- Membrane filters 0.45 micrometers (μm)
- Vacuum source - consistent
- Filter flask, vacuum tubing, forceps
- Stopwatch
- Deionized water

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F-I Procedure

- Measure 200 mL DI water
- Place membrane in filter holder
- Start vacuum
- Add DI water
- Time in seconds to filter DI water
- Discard membrane and DI filtrate
- Repeat for test sample
- Test sample filtrate for water quality

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F-I Procedure

- Filterability Index (FI) = $\frac{\text{Time of Sample}}{\text{Time of DI water}}$
- Good Performance
  - Sand Filters FI < 3
  - High Rate Filters FI < 2
  - Filtered Turbidity < 0.3 NTU

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Troubleshooting

- Incomplete Floc???
  - Take sample after settling basin
  - Put on jar tester and set paddles to slow mix
  - If floc appears, you have incomplete flocculation

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Section 2

Math

Jar Testing

Practical Uses
Velocity Gradient
Laboratory Testing Techniques
Filterability Index
Demonstration

TDEC - Fleming Training Center 1

Key Parameters

- Velocity gradient in the flash mix
- Effective retention time in the flash mix
- Velocity gradient in the flocculator
- Effective retention time in the flocculator
- Surface overflow rate on the sedimentation basin

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Practical Uses for Jar Tests

- Determine coagulant and flocculant dosages
- Determine mixing times
- Chemical addition sequence
- Mixing energies
- Dosages of taste and odor control chemicals
- Dosages of oxidant chemicals

Determine Dose

- Bracket expected "best" dosage
  - If 15 mg/L alum is expected to be best, test 5, 10, 15, 20 , 25 and 30 mg/L
- Change only one variable (i.e. pH adjustment chemical dose) during each test run
  - Perform multiple runs if multiple variable changes are necessary

Rules to Remember

- Keep equipment clean
  - Rinse jars and paddles with DI water
- Use fresh chemicals
- Add chemicals in correct order
- Pre-measure chemicals

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Rules to Remember

- Use 2 liters of water per jar
- Drain water out of sample line before taking sample
- Check pH at flash mix and jar to compare
- Light heats up water – leave off

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Velocity Gradient, G, sec^{-1}

- The power input per unit volume of water
  - How much horsepower the mixing device is supplying to the water to mix the coagulant into the water

  OR
  - How much horsepower is being supplied to increase floc formation in the flocculators

Velocity Gradient, G, sec^{-1}

- The concept of velocity gradient is one of the most important ideas to be understood when conducting jar tests
- The intensity of mixing is generally measured by the velocity gradient
  - A higher number indicates more intense mixing
- Mixing intensities, or velocity gradients, during jar tests should correspond to those in the treatment plant

Velocity Gradient, G, sec^{-1}

- Units = sec^{-1} or ft/sec/ft
- G should decrease as water goes through the treatment process

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How to Find Velocity Gradient

- Consultant or plant engineer
- Manufacturer of unit
- Bid specs, drawings or O&M manual
- Calculations taught in this workshop
- Educated guess/trial and error

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Sedimentation

- Sedimentation basins remove particles by gravity
- The surface loading rate or overflow rate is the most important parameter for sedimentation
- Surface loading corresponds to velocity

Example – Repeat from Slide 123

- The surface overflow rate for a basin is 2,500 gpd/ft^2. What is the settling velocity in cm/min for the basin?
- Settling Velocity, = (0.0025 MGD/ft^2)(2,829.56) cm/min
- Settling Velocity = 7.07 cm/min

Settling Velocity

- To calculate the settling velocity or the rate at which the particles settle, the following conversion factors can be used

Shortcut…

Plant Flow Rate / Surface Area	Multiply By	Settling Velocity
MGD/ft^2	2,829.56	cm/min
gal/min/ft^2	4.0746	cm/min

SLR to Settling Velocity

- A sedimentation tank will remove all particles that exceed the critical velocity for a given overflow rate
- Therefore, the surface loading rate corresponds to the settling velocity and must match that of the process

Settling Velocities cont.

- A sedimentation tank with a surface overflow rate of 1440 gpd/ft^2 removes particles that settle faster than 4 cm/min.
- Particles that settle slower would not be removed

Settling Velocity cont.

Surface Overflow Rate, gpd/ft^2	Settling Velocity, cm/min
180	0.5
360	1.0
720	2.0
1440	4.0
3600	10.0

Note: 1 gpm/ft^2 is equivalent to a settling velocity of 4 cm/min

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Settling Velocities

- General design of alum and ferric sedimentation basins:
  - SOR rates of 400-1000 gpd/ft^2
  - Settling velocities of 1-3 cm/min
- Samples should be taken from 2-10 min in jar tests

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Settling Velocities cont.

- Allowing the water to settle for 30-60 minutes and then taking a sample for turbidity has no relationship to the full-scale system
- This sample should not be used for collecting useful jar test information

Settling Velocities cont.

- Jar tests can be used to determine what percent of the turbidity has a certain settling velocity
- Basin efficiencies can be estimated for a given overflow rate with this info

Ready for Some Math???

Get your calculators out!!

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How to Find Velocity Gradient

- Formula

$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

- V = tank volume, ft^3
- P = horsepower minus 10%
- μ = viscosity, $(lbs)(sec)/ft^2$
- 550 converts HP to WHP

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$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

Horsepower

- P = horsepower (motor and gear unit)
- Take about 10% off for wear and tear
  - 100 hp, use 90 hp
- Get this from your motor nameplate or paperwork

$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

Viscosity

- μ = viscosity of water in force (lb)(sec)/ft^2
- See chart on next slide

Temperature ° C	μ, (lbs)(sec)/ft²	Temperature ° F
2	0.000033613	35.6
4	0.000032731	39.2
6	0.000030747	42.8
8	0.000028964	46.4
10	0.000027846	50
12	0.000024879	53.6
14	0.000024529	57.2
16	0.000023293	60.8
18	0.000022139	64.4
20	0.000021061	68.0
22	0.000020061	71.6
24	0.000019128	75.2
26	0.000018261	78.8
28	0.000017461	82.4
30	0.000016712	86.0

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$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

Volume

- V = volume of the flash mix basin in ft^3
- Square basin, ft^3 = (length, ft)(width, ft)(depth, ft)
- Round basin, ft^3 = (0.785)(Diameter, ft)^2(depth, ft)

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Example

- Motor HP = 6 hp
- Water Temp = 18° C
- Flash mix = 10ft x 10ft x 12 ft deep

- What is G?

Example

- Motor HP = 6
- Water Temp = 18° C
- Flash mix = 10ft x 10ft x 12 ft deep

- P = (6HP)(0.90) = 5.4 hp

- μ = 0.000022139 (from chart)

- V = (10ft)(10ft)(12ft) = 1200 ft^3

$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

Example

$$G = \sqrt{\frac{(550)(5.4\ hp)}{(0.000022139)(1200\ ft^3)}}$$

$$G = \sqrt{\frac{2970}{0.0265668}}$$

$$G = \sqrt{111{,}793.6673}$$

$$G = 334 sec^{-1}$$

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Now What?

- Now what do we do with G now that we have found it?
- Velocity gradient can be correlated to paddle speed in the jar test machine.

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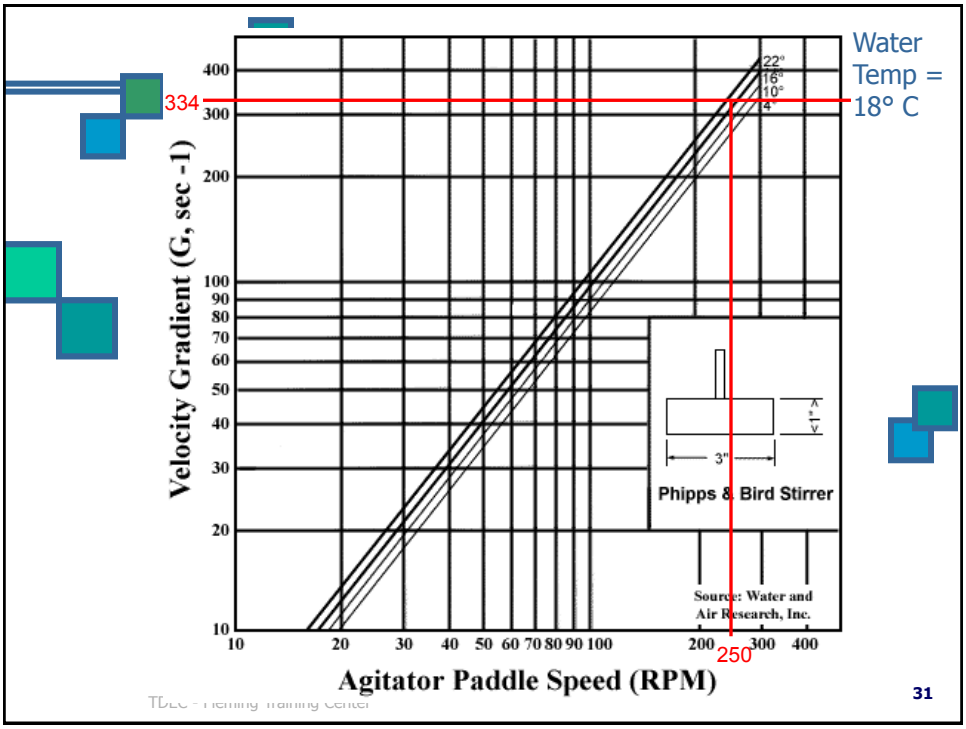

Your Turn

- HP = 3
- Temperature = 16° C
- Volume of flash mix = 8ft x 8ft x 10ft

- What is the velocity gradient and what should be the setting for the jar test paddles?

Example

- Motor HP = 3
- Water Temp = 16° C
- Flash mix = 8ft x 8ft x 10 ft deep

- P = (3 HP)(0.90) = 2.7 hp
- μ = 0.000023293 (from chart)
- V = (8ft)(8ft)(10ft) = 640 ft^3

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$$G = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

Example

$$G = \sqrt{\frac{(550)(2.7\ hp)}{(0.000023293)(640\ ft^3)}}$$

$$G = \sqrt{\frac{1485}{0.01490752}}$$

$$G = \sqrt{99{,}614.1545}$$

$$G = 315.6\ sec^{-1}$$

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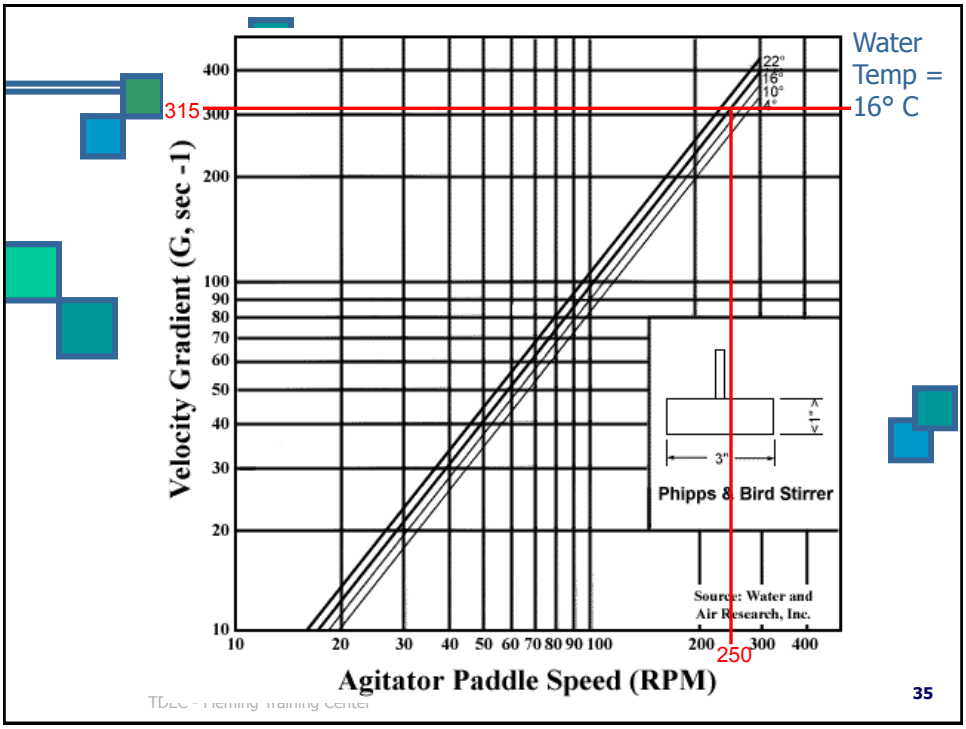

One More Time

- HP = 2
- Temperature = 24° C
- Volume of flash mix = 9ft x 9ft x 10ft

- What is the velocity gradient and what should be the setting for the jar test paddles?

Example

- Motor HP = 2
- Water Temp = 24° C
- Flash mix = 9ft x 9ft x 10 ft deep

- P = (2HP)(0.90) = 1.8 hp
- μ = 0.000019128 (from chart)
- V = (9ft)(9ft)(10ft) = 810 ft^3

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$$G = \sqrt{\frac{(550)(1.8hp)}{(0.000019128)(810\,ft^3)}}$$

$$G = \sqrt{\frac{990}{0.01549368}}$$

$$G = \sqrt{63{,}897.02124}$$

$$G = 252.8\,\sec^{-1}$$

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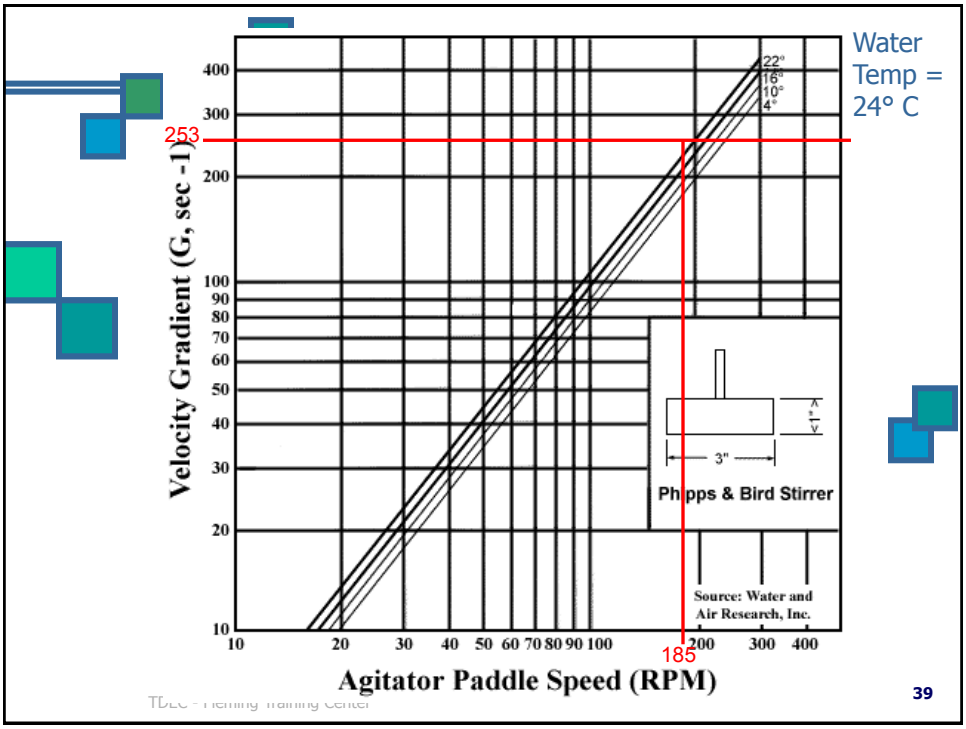

Hydraulic Jumps, Weirs and Baffles

- Formula

$$G = \sqrt{\frac{(62.4)(H)}{(\mu)(T)}}$$

- H= head loss, ft
- μ = viscosity, (lbs)(sec)/ft^2
- T = detention time, sec

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40

$$G = \sqrt{\frac{(62.4)(H)}{(\mu)(T)}}$$

Example

- Temperature = 20° C
  - μ = 0.000021061
- Weir is 2 feet high
- Detention time = 55 seconds

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$$G = \sqrt{\frac{(62.4)(H)}{(\mu)(T)}}$$

$$G = \sqrt{\frac{(62.4)(2\ ft)}{(0.000021061)(55\ sec)}}$$

$$G = \sqrt{\frac{124.8}{0.001158355}}$$

$$G = \sqrt{107{,}738.9919}$$

$$G = 328.2\ sec^{-1}$$

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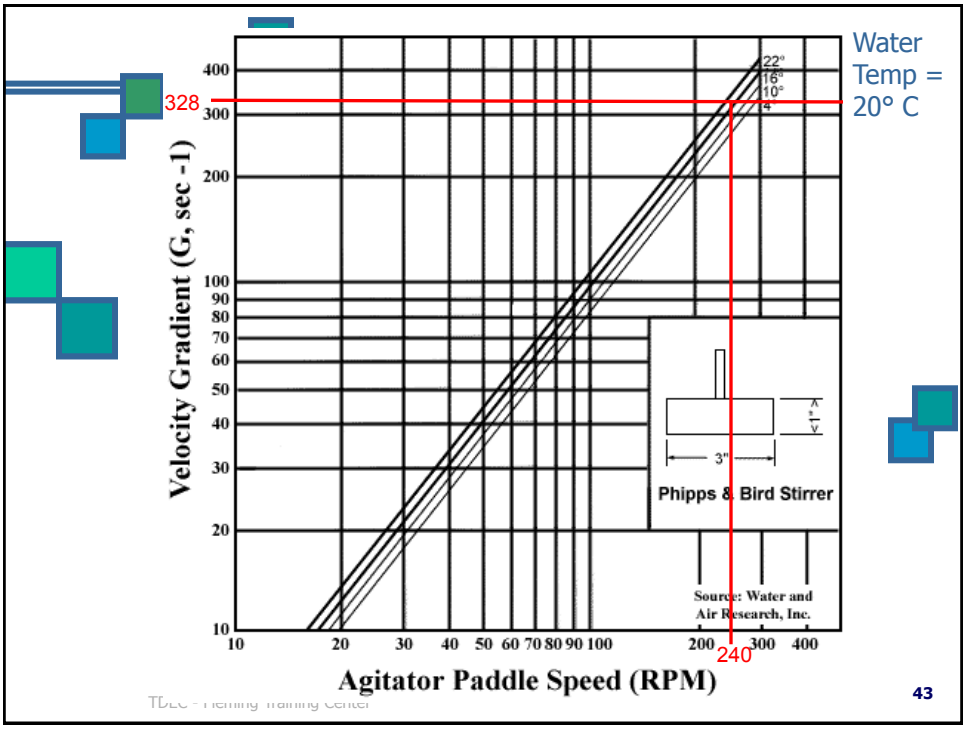

Your Turn

- Temperature = 18° C
- Weir is 2 feet high
- Detention time = 51 minutes = 3060 sec

- What is the velocity gradient and what should be the setting for the jar test paddles?

$$G = \sqrt{\frac{(62.4)(H)}{(\mu)(T)}}$$

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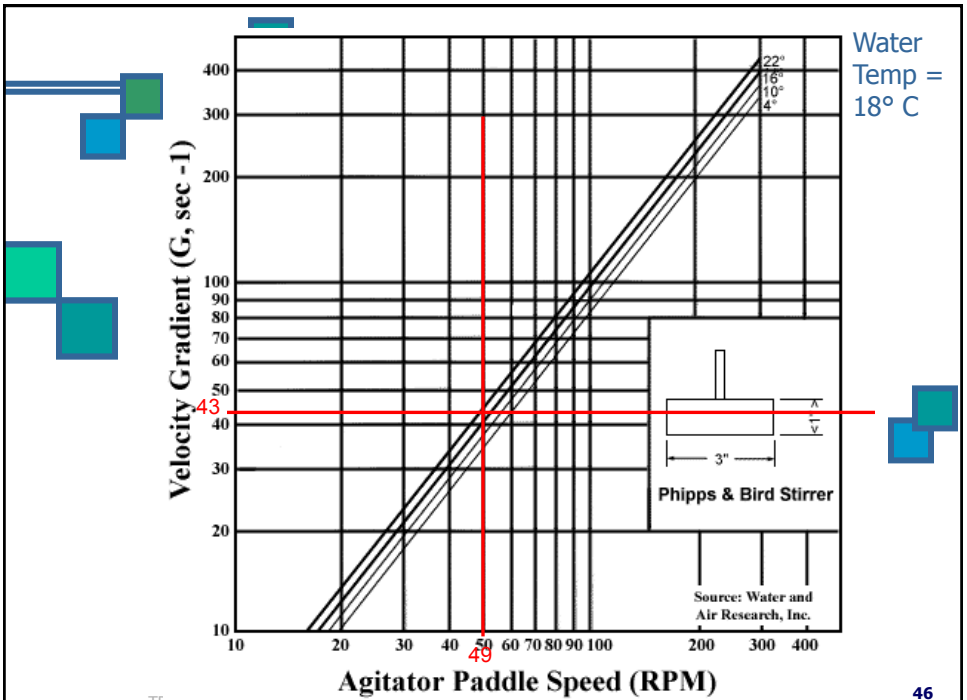
45



46

Variable Speed Mixers

$$\frac{G_1}{G_2} = \left(\frac{N_1}{N_2}\right)^{3/2}$$

OR

$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- G1 = G_{max}
- G2 = Velocity Gradient
- N1 = RPM_{max}
- N2 = RPM's

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47

Example

- Water Temp = 16° C
- Flash mix = 12ft x 12ft x 10ft
- 3 HP motor
- Max RPM's = 2.5

- Vary Drive
  - 10 = 2.5 rpm
  - 9 = 2.25 rpm
  - 8 = 2.0 rpm
  - 7 = 1.75 rpm
  - 6 = 1.5 rpm
  - 5 = 1.25 rpm
  - 4 = 1.0 rpm = N_2
  - 3 = 0.75 rpm
  - 2 = 0.5 rpm
  - 1 = 0.25 rpm

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48

- P = (3 hp)(0.90) = 2.7 hp
- μ = 0.000023293 (from chart)
- V = (12ft)(12ft)(10ft) = 1440 ft^3

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$$G_1 = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

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$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- G1 = G_{max}
- G2 = Velocity Gradient
- N1 = RPM_{max}
- N2 = RPM's

This is the velocity gradient at vary drive 4 with 1.0 rpm

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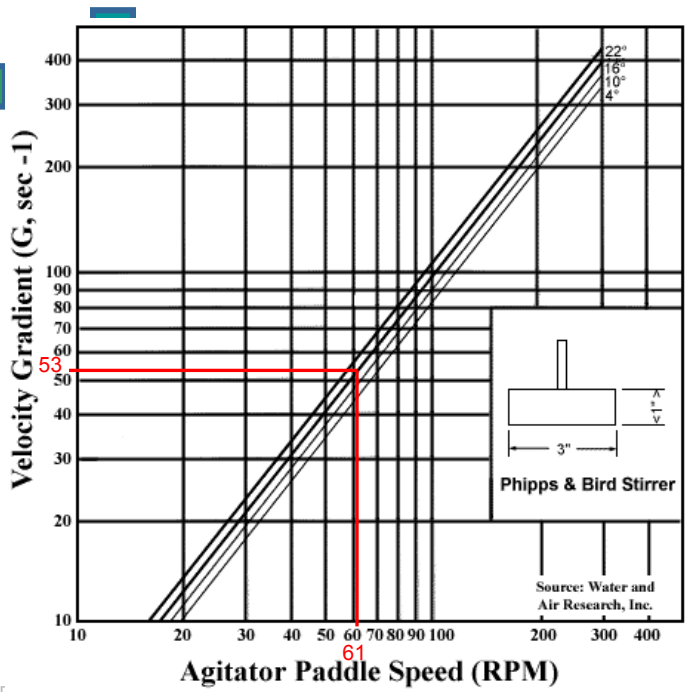
51

Water Temp = 16° C



52

- Using 2.5 for N_1 and 210 for G_1, solve for G_2 at all other RPM's

Setting	Flocculator RPM	G_2	Jar Test RPM
10	2.5	210	187
9	2.25	179	162
8	2.0	150	137
7	1.75	123	115
6	1.5	98	100
5	1.25	74	80
4	1.0	53	61
3	0.75	35	43
2	0.5	19	27
1	0.25	6.6	<10

Calculating Stirring Times

- Stirring Time, min = $\frac{\text{(Plant Capacity, gpm)(DT, min)}}{\text{Actual Flow Rate, gpm}}$
- Detention Time, min = $\frac{\text{Tank Vol, gal}}{\text{Flow Rate, gpm}}$

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- What if your jar test machine won't give you a high enough G (velocity gradient)?
  - You must mix longer to compensate for the decreased velocity gradient
- $G_1T_1 = G_2T_2$

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Example

- Velocity Gradient = 1000 sec^{-1}
- Time = 15 sec
- Temp = 22°C

- Our Phipps & Bird machine will only go up to 105 rpm's, which is equivalent to ~ 100 sec^{-1}

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$$G_1 T_1 \equiv G_2 T_2$$

$$T_1 \equiv \frac{(G_2)(T_2)}{G_1}$$

$$T_1 \equiv \frac{(1000\ sec^{-1})(15\ sec)}{100\ sec^{-1}}$$

$$T_1 = 150\ sec@105\ rpm$$

$T_1 = T_{max}$ = time to use in jar test, sec
$G_1 = G_{max}$= maximum G for jar test machine, sec^{-1}
T_2 = actual process detention time, sec
G_2 = calculated velocity gradient, sec^{-1}

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Sedimentation

- Does surface loading rate influence sedimentation?
  - Yes – this is one of the most important factors
  - Also knows as Surface Overflow Rate
- SOR = $\frac{\text{Basin Flow Rate, gpd}}{\text{Basin Surface Area, ft}^2}$

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Example

- A water plant has four sedimentation basins. It treats 6 MGD. The flow is split equally between all four basins. The basins are 30 feet long and 20 feet wide. What is the surface overflow rate for each basin in gpd/ft^2?

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$$gpd/basin = \frac{6{,}000{,}000\ gpd}{4\ basins}$$

$$gpd/basin = 1{,}500{,}000\ \ gpd/basin$$

$$SOR = \frac{1{,}500{,}000\ gpd}{(30\ ft)(20\ ft)}$$

$$SOR = \frac{1{,}500{,}000\ gpd}{600\ ft^2}$$

$$SOR = 2{,}500\ {}^{gpd}\!/_{ft^2}$$

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Conversion of SOR to Settling Velocities

- Settling Velocity, cm/min = $\frac{(SOR,\ gpd/ft^2)(3785\ cm^3/gal)}{(1440\ min/day)(929\ cm^2/ft^2)}$

1 cm^3 = 1 mL
3785 mL = 1 gal
Therefore, 3785 cm^3 also = 1 gal

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Example

- The surface overflow rate for a basin is 2,500 gpd/ft^2. What is the settling velocity in cm/min for the basin?
- Settling Velocity, cm/min = $\frac{(\text{SOR, gpd/ft}^2)(3785\ \text{cm}^3/\text{gal})}{(1440\ \text{min/day})(929\ \text{cm}^2/\text{ft}^2)}$
- Settling Velocity, cm/min = $\frac{(2{,}500,\ \text{gpd/ft}^2)(3785\ \text{cm}^3/\text{gal})}{(1440\ \text{min/day})(929\ \text{cm}^2/\text{ft}^2)}$
- Settling Velocity = 7.07 cm/min

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Settling Velocities

Settling Velocity, cm/min	Sampling Time, min
0.5	20
1.0	10
2.0	5
4.0	2.5
10.0	1

Chart based on a sample depth in the jar of 10 cm

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- $\frac{10\text{cm}}{4\text{ cm/min}} = 2.5$ min
- So, at $\frac{10\text{ cm}}{7\text{ cm/min}} = 1.4$ min till sampling time

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Coagulation/Flocculation Math

Volume

1. A flash mix chamber is 4 feet wide by 5 feet long and contains water to a depth of 3 feet. What is the volume in gallons of water in the flash mix chamber?

2. A flocculation basin is 50 feet long by 20 feet wide and contains water to a depth of 8 feet. What is the volume in gallons of the water in the basin?

3. A flocculation basin is 40 feet long by 16 feet wide and contains water to a depth of 8 feet. How many gallons of water are in the basin?

4. A flash mix chamber is 5 feet square and contains water to a depth of 42 inches. What is the volume in gallons of water in the flash mixing chamber?

5. A flocculation basin is 25 feet wide by 40 feet long and contains water to a depth of 9 feet 2 inches. What is the volume in gallons of water in the flocculation basin?

Detention Time

6. The flow to a flocculation basin is 3,625,000 gal/day. If the basin is 60 feet long by 25 feet wide and contains water to a depth of 9 feet, what is the detention time (in minutes) of the flocculation basin?

7. A flocculation basin is 50 feet long by 20 feet wide and has a water level of 8 feet. What is the detention time (in minutes) in the basin if the flow to the basin is 2.8 MGD?

8. A flash mix chamber is 6 feet long, 5 feet wide and 5 feet deep. It receives a flow of 9 MGD. What is the detention time (in seconds) in the chamber?

9. A flocculation basin is 50 feet long by 20 feet wide and has a water depth of 10 feet. If the flow to the basin is 2,250,000 gal/day, what is the detention time in minutes?

10. A flash mix chamber is 4 feet square and has a water depth of 42 inches. If the flash mix chamber receives a flow of 3.25 MGD, what is the detention time in seconds?

Dry Feeder Settings

11. The desired dry alum dosage, as determined by the jar test, is 10 mg/L. Determine the lb/day setting on a dry alum feeder if the flow is 3,450,000 gal/day.

12. Jar tests indicate that the best polymer dose for a water sample is 12 mg/L. If the flow to be treated is 1,660,000 gal/day, what should the dry chemical lb/day feed setting be?

13. Determine the desired lb/day setting on a dry alum feeder if jar tests indicate an optimum dose of 12 mg/L and the flow to be treated is 2.66 MGD.

14. The desired dry alum dose is 9 mg/L, as determined by a jar test. If the flow to be treated is 940,000 gal/day, how many lb/day dry alum will be required?

15. A flow of 4.10 MGD is to be treated with a dry polymer. If the desired dose is 13 mg/L, what should the dry chemical feeder in lb/day setting be?

16. Calculate the actual chemical feed rate in pounds per day if a container is placed under a chemical feeder and 2.3 pounds are collected during a 30-minute period.

17. During a 24-hour period, a flow of 1,920,000 gal/day is treated. If 42 pounds of polymer were used for coagulation during that 24-hour period, what is the polymer dosage in mg/L?

Liquid Feeder Settings

18. Jar tests indicate that the best alum dose for a unit process is 7 mg/L. The flow to be treated is 1.66 MGD. Determine the gal/day setting for the alum solution feeder if the liquid alum contains 5.24 pounds of alum per gallon of solution.

19. The flow to a plant if 3.43 MGD. Jar testing indicates that the optimum alum dose is 12 mg/L. What should the gal/day setting be for the solution feeder if the alum solution is a 55% solution?

20. Jar tests indicate that the best alum dose for a unit process is 10 mg/L. The flow to be treated is 4.13 MGD. Determine the gal/day setting for the alum solution feeder if the liquid alum contains 5.40 pounds of alum per gallon of solution.

21. Jar tests indicate the best liquid alum dose for a unit process is 11 mg/L. The flow to be treated is 880,000 gal/day. Determine the gal/day setting for the liquid alum chemical feeder if the liquid alum is a 55% solution.

22. A flow of 1,850,000 gal/day is to be treated with alum. Jar tests indicate that the optimum alum dose is 15 mg/L. If the liquid alum contains 640 mg alum per milliliter solution, what should be the gallons per day setting for the alum solution feeder?

23. The desired solution feed rate was calculated to be 40 gal/day. What is this feed rate expressed at milliliters per minute (mL/min)?

24. The desired solution feed rate was calculated to be 34.2 gal/day. What is this feed rate expressed at milliliters per minute (mL/min)?

25. The optimum polymer dose has been determined to be 10 mg/L. The flow to be treated is 2,880,000 gal/day. If the solution to be used contains 55% active polymer, what should the solution chemical feeder setting be in milliliters per minute (mL/min)?

26. The optimum polymer dose for a 2,820,000 gal/day flow has been determined to be 6 mg/L. If the polymer solution contains 55% active polymer, what should the solution chemical feeder setting in milliliters per minute be? Assuming the polymer solution weighs 8.34 lbs/gal.

27. Jar tests indicate that the best alum dose for a unit process is 16 mg/L. The liquid alum contains 5.40 pounds alum per gallon of solution. What should the setting be on the solution chemical feeder in milliliters per minute (mL/min) when the flow to be treated is 3.45 MGD?

Chemical Usage

28. Based on the amount of chemical used each day, what was the average chemical use in pound/day for the following week: Monday, 81 pounds; Tuesday, 73 pounds; Wednesday, 74 pounds; Thursday 66 pounds; Friday 79 pounds; Saturday 80 pounds and Sunday, 82 pounds.

29. The average chemical use at the plant is 90 lbs/day. If the chemical inventory in stock is 2200 pounds, how many days supply is this?

30. The chemical inventory in stock is 889 pounds. If the average chemical use at the plant is 58 pounds per day, how many days supply is this?

31. The average gallons of polymer solution used each day at a treatment plant are 88 gal/day. A chemical feed tank has a diameter of 3 feet and contains solution to a depth of 3 feet 4 inches. How many days supply is in the solution tank?

32. Jar tests indicate that the optimum polymer dose for a unit process is 2.8 mg/L. If the flow to be treated is 18 MGD, how many pounds of dry polymer will be required for a 30-day period?

Velocity Gradient

33. What is your velocity gradient for a flash mix that is 6 feet square by 8 feet deep. You have a 5 hp motor and the water temperature is 20°C.

34. What is your velocity gradient for a flash mix that is 10 feet by 10 feet and 12 feet deep. You have a 8 hp motor and the water temperature is 22°C.

35. Your flocculators are 20 feet square by 16 feet deep. You have a variable speed drive that has 3 hp and the maximum RPM's equals 2.5 and you have the variable speed set on 6. The water temperature is 18°C. Find your velocity gradient.

Vary Drive

- 10 = 2.5 rpm
- 9 = 2.25 rpm
- 8 = 2.0 rpm
- 7 = 1.75 rpm
- 6 = 1.5 rpm
- 5 = 1.25 rpm
- 4 = 1.0 rpm
- 3 = 0.75 rpm
- 2 = 0.5 rpm
- 1 = 0.25 rpm

36. Your second set of flocculators is 20 feet square by 16 feet deep. You have a variable speed drive that has 3 hp and the maximum RPM's equals 2.5 and you have the variable speed set on 3. The water temperature is 18°C. Use the chart above. Find your velocity gradient.

37. Your old jar test machine will only go up to 125 rpm's, which is equivalent to about 140 sec^{-1}. Your water temperature is 22°C. You wanted to achieve a mixing velocity of 600 sec^{-1} for 16 seconds. How long must you mix to make up for the slow mixing?

38. Your old jar test machine will only go up to 80 rpm's, which is equivalent to about 75 sec^{-1}. Your water temperature is 16°C. You wanted to achieve a mixing velocity of 153 sec^{-1} for 13 seconds. How long must you mix to make up for the slow mixing?

Surface Overflow Rate

39. A rectangular sedimentation basin is 60 feet long and 25 feet wide. When the flow is 510 gal/min, what is the surface overflow rate in gal/day/ft^2?

40. A circular clarifier has a diameter of 70 feet. If the flow to the clarifier is 1610 gal/min, what is the surface overflow rate in gal/day/ft^2?

41. A rectangular sedimentation basin receives a flow of 540,000 gal/day. If the basin is 50 feet long and 20 feet wide, what is the surface overflow rate in gal/day/ft^2?

42. The surface overflow rate for a basin is 2,300 gal/day/ft^2. What is the settling velocity in cm/min?

43. The surface overflow rate for a basin is 1,500 gal/day/ft^2. What is the settling velocity in cm/min?

Answers:

1. 448.8 gal
2. 59,840 gal
3. 38,298 gal
4. 654.5 gal
5. 68,567 gal
6. 40 min
7. 30.8 min
8. 10.8 sec
9. 48 min
10. 11.1 sec
11. 288 lbs/day
12. 166 lbs/day
13. 266 lbs/day
14. 70.6 lbs/day
15. 445 lbs/day
16. 110.4 lbs/day
17. 2.6 mg/L
18. 18.5 gpd
19. 74.8 gpd
20. 63.8 gpd
21. 17.6 gpd
22. 43.3 gpd
23. 105 mL/min
24. 89.9 mL/min
25. 137.6 mL/min
26. 80.9 mL/min
27. 224 mL/min
28. 76.4 lbs/day
29. 24.4 days
30. 15.3 days
31. 2 days
32. 12,610 lbs
33. 638 sec^{-1}
34. 406 sec^{-1}
35. 47 sec^{-1}
36. 17 sec^{-1}
37. 69 sec
38. 27 sec
39. 489.6 gpd/ft^2
40. 602.7 gpd/ft^2
41. 540 gpd/ft^2
42. 6.5 cm/min
43. 4.2 cm/mi

Section 3

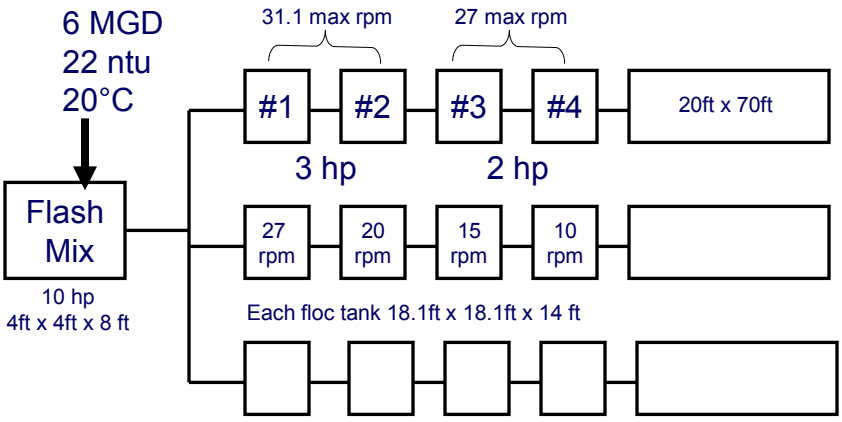
Plant Examples

PLANT EXAMPLES

1

Plant Example

Jar Tester maxes out at 400 sec^{-1}



2

Plant Example

- We need to replicate in the lab how our plant performs
  - Detention times
  - Velocity gradients (RPMs in lab)
  - Surface overflow rate
  - Sampling time

3

Step 1 – Flash Mix

- Find G (velocity gradient)
- Find Detention time for Flash Mix in seconds

4

Flash Mix

5

Flash Mix

6

Flash Mix

- Jar tester max 300 rpm ≈ 400 sec^{-1}

7

Step 2 - Flocculators

- Find G_2 for Flocculator #1
- Plug velocity gradient into chart to determine paddle RPMs on jar tester
- Repeat for any additional flocculators
- ** Be sure to note any changes in dimensions, RPMs and HP

8

Flocculators

$$G_1 = \sqrt{\frac{(550)(P)}{(\mu)(V)}}$$

9

Flocculator #1

$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- Plug this into Phipps Bird Chart

10

Flocculator #2

$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- Plug this into Phipps Bird Chart

11

Flocculator #3

$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- Plug this into Phipps Bird Chart

12

Flocculator #4

$$G_2 = \frac{G_1}{\left(\frac{N_1}{N_2}\right)^{3/2}}$$

- Plug this into Phipps Bird Chart

13

Flocculators

14

Jar Test Sequence

- Flash 46.7 sec @ 300 rpm
- Then 25 min @ 98 rpm
- Then 25 min @ 69 rpm
- Then 25 min @ 49 rpm
- Then 25 min @ 30 rpm

15

Step 3 – Sedimentation Basin

- Find Surface Overflow Rate for sedimentation basin
- Find sampling time for sedimentation basin

16

Settling Time

17

Settling Velocity

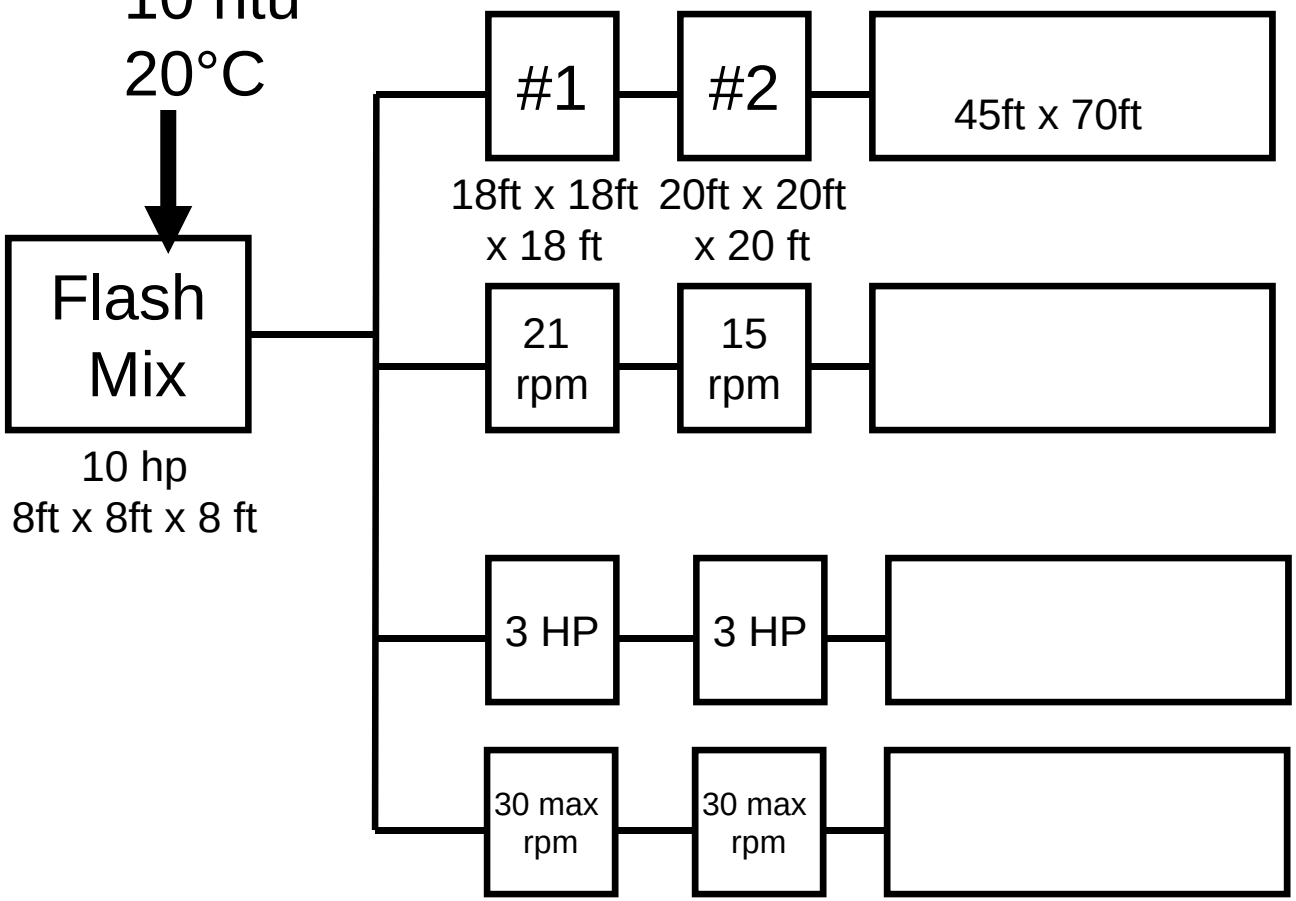
Settling Velocity, cm/min	Sampling Time, min
0.5	20
1.0	10
2.0	5
4.0	2.5
10.0	1

Sample at 2.5 min and 10 min

18

Plant Example

8 MGD
10 ntu
20°C



Plant Example #2

Flash Mix

Velocity Gradient = _____

Detention time = _____

Jar test max RPM = _____

Time correction = _____

Flocculator #1

Velocity Gradient = _____

Jar Test rpm = _____

Detention Time = _____

Flocculator #2

Velocity Gradient = _____

Jar Test rpm = _____

Detention Time = _____

Sedimentation

Surface Overflow Rate= _____

Settling Velocity = _____

Sampling Time = _____

Section 4

Laboratory

Jar Testing

Water Treatment Troubleshooting and Problem Solving

Jar Testing

- Introduced in 1918 and has remained the most common method for evaluating alternative coagulation and flocculation control strategies for establishing chemical dosages
- There is no standardized procedure for conducting jar tests
  - So we must have a uniform or standardized approach to conducting jar tests

Jar Testing

- A series of sample containers and a mechanical stirring device
- The water to be tested is placed in the containers and the treatment chemicals are added during stirring
- There is an initial period of rapid stirring to facilitate dispersion of the chemicals
- The chemically treated water is then slow mixed, or flocculated for a period of time
- The mixing is then stopped, and the floc is allowed to settle

Jar Testing

- During the settling step, samples of the water can be collected at timed intervals and analyzed
- Following the settling step, samples of the water can be collected, filtered through either a 0.45 µm filter or a 1 µm filter, and analyzed for UV-absorbance, total organic carbon (TOC) and/or trihalomethane (THM) formation potential

Application

- Principle applications of jar tests are to optimize existing plant operations
- Used for the selection and/or determination of
  - Coagulant dosage
  - Coagulant aid selection and dosage
  - Sequence of chemical addition
  - Optimum pH of coagulation
  - Improved coagulation/flocculation for THM precursor removal
  - Impact of oxidant dosages and conditions

Key Elements

- Planning
  - Define the purpose and goals of the study
  - Select the water to be tested
  - Determine the information required
  - Establish the testing conditions
  - Develop the testing program
- Identify and prepare treatment chemicals
- Conduct the jar tests
- Analyze the data

Planning the Jar Test

- Establish Purpose and Goals
  - Selection of coagulant dosage
  - Selection of coagulant aid dosage
  - Determination of optimum pH of coagulation
  - Optimization of THM precursor removal
- Selection of Water to be Tested
  - Raw water
  - Pre-sedimentation basin effluent
  - Oxidant contactor effluent
  - Other pre-coagulant addition location

Planning the Jar Test

- Information Required
  - Water quality parameters for coagulant determination
    - Turbidity
    - True color
    - pH
    - Filtered UV-254
  - Water quality parameters for coagulant aid determination
    - Turbidity

Planning the Jar Test

- Information Required
  - Water quality parameters for optimum pH determination
    - Turbidity
    - pH
    - UV-254

Planning the Jar Test

- Example Testing Program – Selecting coagulant dose
  - Perform initial screen of a broad range of coagulant dosages
    - Dosages: 10, 20, 30, 40, 50, 60 mg/L
    - pH of coagulation = 6.5 for alum, lower for iron coagulants
    - Use the coagulant aid type and dosage currently in use in all six jars
    - Measure the primary water quality parameters
      - Turbidity
      - pH
      - UV-254 (if equipped)

Planning the Jar Test

- Example Testing Program – Selecting coagulant dose

  Step 1 concluded optimum dosage of 20 mg/L
  - Perform second jar test based on initial jar test
    - Dosages: 14, 17, 20, 23, 26 mg/L
    - pH of coagulation and coagulant aid type and dosage would remain the same
    - Optimum coagulant dosage defined as:
      - Acceptable turbidity removal
      - Minimizing the filtered UV-absorbance (if applicable)

Planning the Jar Test

- Testing Conditions
  - Standard procedure for establishing jar testing conditions
    - Utilize the rapid mix and flocculation mixing intensities and detention times in use at the full-scale plant
    - During the settling step, set a sampling time that would correspond to the surface loading rate or detention time of the settling basin

Equipment

- Jar test apparatus
- Analytical equipment

Preparation of Chemicals

- Chemical stock solutions must be diluted for jar test
- Amount of dilution required dependent upon dosage and minimum amount of chemical that can be accurately measured
- Effectiveness of coagulants and coagulant aids can be affected by dilution
  - Dilutions less than 0.1% solution may loose its effectiveness due to hydrolysis
  - Dilutions will degrade over time
    - Should be made up on a weekly basis

Jar Test Procedure

- Initial Preparation
  - Define and record
    - Objective of the study
    - Chemicals to be used, points of application and dosage
    - Water to be tested
  - Prepare all chemical stock solutions
  - Calibrate all analytical equipment
  - Clean all apparatus prior to use
    - Wipe jars and paddles and rinse with warm water between tests
    - Rinse all pipettes and syringes

Jar Test Procedure

1. Collect at least 12 liters of water to be tested (3.2 gal)
2. Measure and record the initial parameters of interest
   - Temperature, pH, turbidity, color, etc
3. Fill square jars up to the 2-liter mark
4. Position jars so jar test paddles are centered
5. Fully lower paddles and tighten thumb screw
6. Ready and arrange all chemicals to be added
7. Set rapid mix speed on the jar test stirrer
8. Add predetermined doses of chemicals into jars (all at the same time) and being timing the rapid mix step

Jar Test Procedure

9. Continue rapid mix for predetermined time
10. Reduce mixing speed for flocculation and begin timing flocculation period
11. Stop the mixing at the end of predetermined flocculation time an d begin timing the settling period
12. Withdraw samples at the appropriate intervals
    - waste the water in sampling tube prior to collecting each sample
13. Analyze the timed samples for turbidity and record the results

Jar Test Procedure

14. Measure and record the pH of each jar
15. Conduct all other analyses required for the test
    - Alkalinity
    - Temperature
    - etc

Jar Test Procedure

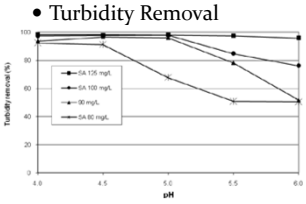
- Potential sources of error
  - Deposition of coagulant aid on the paddles or on the walls of the jar
  - Improper preparation of the chemical stocks
  - Excessive aging of the chemical stocks
  - Incomplete dispersion of the chemicals added to the jars
  - Measurement error of chemicals
  - Use of chemicals from different source than t hose used in the full scale plant

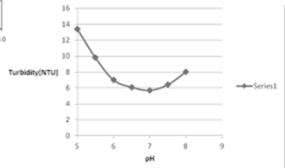
Jar Test Interpretation

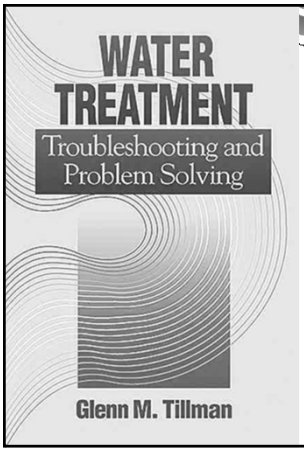
- Performed to select
  - Optimum coagulant dose
  - Optimum pH of coagulation
  - Optimum coagulant aid dose
- Selection based on turbidity and NOM removal
- Use results to prepare a graph
  - Turbidity as a function of the time of sampling
  - Filtered UV-absorbance as a function of dose or pH
  - TOC as a function of dose or pH

Jar Test Interpretation

- Turbidity Removal







- Tillman, Glenn M. Water Treatment Troubleshooting and Problem Solving. Chelsea, Michigan: Ann Arbor Press, Inc., 1996. Print.

Conducting the Jar Test

Before starting:

- Define study goals
- Define testing parameters
- Have testing and analytical equipment ready
    - Working and clean
- Prepare reagent solutions
    - Properly labeled and mixed
- Data sheet available
    - Should be a good guide for conducting

---

1. Treatment performance is often expressed in terms of percentage removal. Therefore an important beginning step is to determine the quality of the raw water to be tested. Such data may be obtained from treatment plant records or determined during the jar test. Also, pH and alkalinity data may help determine necessary additions of acid or base

2. Enter the names and concentrations of the chemicals to be added on the data sheet. This information is necessary to determine the volumes of the chemical to be added during the jar test.

3. Enter the G values for the rapid mix and flocculation stages of the full-scale plant on the data sheet. If the effect of varying mixing intensities is to be evaluated, use the appropriate range of G values. Convert these values to the appropriate rpm in the jar tests.
    a. Refer to the Phipps & Bird graph to determine correct rpm value based on jar test equipment used.

4. Enter the detention times for the rapid mix and the flocculation stages of the full-scale plant in the data sheet. If the effects of the detention times are to be evaluated, use an appropriate range of durations.

5. Enter the coagulant doses on the data sheet. If the test will determine an optimum coagulant dose, it is useful to select doses in increments of 10 mg/L for alum, or equivalent doses if other coagulants are to be tested. Smaller increments may be used for fine-tuning the optimum coagulant dose. Then calculate the volume of coagulant to be dispensed into the jar to obtain the desired coagulant dose.

6. If applicable, proceed with all the other chemicals in a similar manner.

7. Based on the surface loading or overflow rate of the sedimentation basin of the full-scale plant, determine the critical settling velocity as outlined in the discussion. Divide the depth of the sampling port on the jars in centimeters by the settling velocity to obtain the sampling time in minutes.

8. Fill the jars with the water to be tested, and position them under the stirring apparatus so they are centered with respect to the impeller and shafts.

9. Lower the impellers or paddles so that they are about one-third from the bottoms of the jar.

10. Begin the flash mix period based on the previously determine values. Do not forget to record the starting time Dispense the desired doses of chemicals as rapidly as possible into the jars. Dispense the chemicals in the same sequence as the full scale plant, unless the effect of moving the point of application is to be evaluated.

11. After the rapid mix period, decrease the mixing speed to the predetermined value for the flocculation period. At this point, the coagulation pH is typically measured.

12. After the flocculation period, stop the mixer and remove the paddles from the jars. Collect samples at the times previously calculated to simulate the full-scale sedimentation plants. Sample withdrawal may be accomplished either by the use of a syringe, a fixed sampling port, or a pipette. The first portion of the samples taken from a fixed port should be discarded. When using a syringe, samples should be taken from the same depth as the fixed port.

13. After sampling, conduct the laboratory analysis, observing holding times required for specific analytical applications.

14. Enter laboratory results on the data sheet.

Fleming Training Center

Jar #		1	2	3	4	5	6
Rapid Mix	RPM						
	Duration						
Flocculation	RPM						
	Duration						
	RPM						
	Duration						
	RPM						
	Duration						
	RPM						
	Duration						

Chemicals	mg/L	mL or µ/L	mg/L	mL or µ/L	mg/L	mL or µ/L	mg/L	mL or µ/L	mg/L	mL or µ/L	mg/L	mL or µ/L
Type Concentration Specific Gravity												
Type Concentration Specific Gravity												

Time of Settling, min	Depth of Sampling, cm	Settling Velocity, cm/min	Tubidity, ntu	% Remaining	Tubidity, ntu	% Remaining	Tubidity, ntu	% Remaining	Tubidity, ntu	% Remaining	Tubidity, ntu	% Remaining	Tubidity, ntu	% Remaining
	10													
	10													
	10													
	10													
	10													
	10													
Floc Size														
pH														
Color														

Raw Water	Turbidity		Color		pH	

Fleming Training Center

Date			Time			Analyst				
Jar	Chemical	Raw Turbidity	Raw pH	Chemical Dose, mg/L	Specific Gravity	Chemical Purity, %	uL used for 2 L jar	Settled pH	Settled Turbidity at 2.5 min	Settled Turbidity at 10 min
1										
2										
3										
4										
5										
6										

Date			Time			Analyst				
Jar	Chemical	Raw Turbidity	Raw pH	Chemical Dose, mg/L	Specific Gravity	Chemical Purity, %	uL used for 2 L jar	Settled pH	Turbidity at 2.5 min	Turbidity at 10 min
1										
2										
3										
4										
5										
6										