

Coagulation and Flocculation

- **Coagulation is a physical and chemical reaction occurring between the "ALKALINITY" of the water and the coagulant added to the water which results in the formation of insoluble flocs (floc that will not dissolve).**
- **The reaction is very complex and is effected by a variety of factors including :**
 - Temperature
 - pH
 - Alkalinity
 - Specific conductance
- **Changes in factors may have an impact on the clumping together of floc during the coagulation-flocculation process**

What is specific conductance? it is the ability of a water to conduct an electrical current; provides an estimate of the amount of dissolved solids

1

Purpose of Coagulation and Flocculation

Remove particulate impurities (turbidity) from the water

- Turbidity is the cloudy appearance of water caused by small suspended particles
- Commonly referred to as non-settleable or colloidal solids



2

Particles in Water

- Chemicals in solution (have been completely dissolved in the water).
- Colloidal solids, also known as nonsettleable solids (do not dissolve in water although they are electrically charged).
- Suspended, or settleable solids (will settle out of water over time).

3

Conventional Coagulation/Flocculation Process

The diagram illustrates the conventional water treatment process. It starts with 'raw water' entering a 'screen' (with 'watershed protection' noted). The water then goes to 'chemical addition', followed by 'coagulation' and 'flocculation' tanks. From there, it can go to 'direct filtration' or 'sedimentation'. 'Sedimentation' produces 'waste sludge' which is recycled back to the 'coagulation' stage. The water then goes to 'filtration' (with a lightbulb icon) and 'disinfection'. Finally, the water is sent to the 'distribution system'. A 'backwash recycle' line is also shown.

- Pretreatment
- Chemical Feed
- Flash Mixing
- Coagulation & Flocculation (require detention times up to 30 minutes)
- Sedimentation
- Filtration
- Disinfection

4

When problems with the floc formation in the flocculation basin occur, you should NOT adjust the ?

- A. Chlorine dosage
- B. Coagulant dosage
- C. Adjust alkalinity or pH
- D. Flocculator mixing intensity

5

Pretreatment Considerations in the Coagulation/Flocculation Process

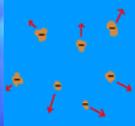
The photograph shows a tall, rectangular metal water filtration unit with a hopper at the top and a collection tray at the bottom, standing on a concrete surface.

Factors that May Dictate Pretreatment

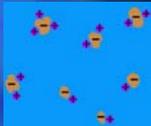
- Leaves, plant material and silt
- Seasonal raw water quality changes caused by drought, high water or temperature changes
- Potential upstream pollution
- Wind conditions
- Algae blooms
- Bacterial problems

6

Particle Removal by Coagulation



Negatively charged particles repel each other due to electricity.



Positively charged coagulants attract to negatively charged particles due to electricity.

- Coagulants neutralize negative charged particles
- Allows particles to come closer and form larger clumps
- Provides "agglomeration sites" for larger floc

7

Factors Affecting the Effectiveness of the Coagulation Process

- Best pH (pH Range: Al, 5 – 7 ; Fe, 5 – 8)
- Alkalinity of water (> 30 PPM residual)
- Concentration of Salts (affect efficiency)
- Turbidity (constituents and concentration)
- Type of Coagulant used (Al and Fe salts)
- Temperature (colder requires more mixing)
- Adequacy of mixing (dispersion of chemical)

8

Chemical Coagulants Used in Water Treatment

Chemical Name	Chemical Formula	Primary Coagulant	Coagulant Aid
Aluminum Sulfate	Al ₂ (SO ₄) ₃	X	
Ferrous Sulfate	FeSO ₄	X	
Ferric Sulfate	Fe ₂ (SO ₄) ₃	X	
Ferric Chloride	FeCl ₃	X	
Cationic Polymer (+)	Various	X	X
Calcium Hydroxide	Ca(OH) ₂	X ^a	X
Calcium Oxide	CaO	X ^a	X
Sodium Aluminate	Na ₂ Al ₂ O ₄	X ^a	X
Bentonite	Clay		X
Calcium Carbonate	CaCO ₃		X
Sodium Silicate	NaSiO ₃		X
Anionic Polymer (-)	Various		X
Nonionic Polymer	Various		X

^a - Used as primary coagulant in water softening processes.
Alum is the most commonly used coagulant

Primary Coagulants

- Primary coagulants are always used in the coagulation/flocculation process. Alum and ferric sulfate are most commonly used.
- Different sources of water need different coagulants to react over a wider pH range.
- Primary coagulants have multivalent charges (+2, +3, +4) which allow them to react with the negatively charged colloidal materials in the water.
- All of the coagulant chemicals will remove alkalinity from the water.

10

Coagulant Aids

- Add density to slow-settling floc and add toughness to the flocs so that they will not break up during mixing and settling processes.
- Not always required and are generally used to reduce flocculation time.
- Effective at extending pH ranges for primary coagulant performance.
- Most are expensive.

11

Raw Water Parameter	Chemical Consideration
Alkalinity <i>Alkalinity is a measure of the ability to neutralize acid. Alkalinity levels are typically expressed as calcium carbonate (CaCO₃) in mg/L.</i>	Alkalinity influences how chemicals react with raw water. Too little alkalinity will result in poor floc formation, so the system may want to consider adding a supplemental source of alkalinity (such as lime, soda ash, or caustic soda). Beware that these supplemental sources of alkalinity may raise the pH of the water, and further pH adjustment may be needed to obtain proper floc formation. Systems should discuss this issue with a technical assistance provider or a chemical supplier. One rule of thumb is that alum consumes half as much alkalinity as ferric chloride. ¹
Alkalinity < 50 mg/L	This concentration of alkalinity is considered low, and acidic metallic salts, such as ferric chloride or alum, may not provide proper floc formation. Systems may want to consider a high basicity polymer, such as polyaluminum hydroxychloride (PACl), or an alum/polymer blend. ¹
Increase in total organic carbon	More coagulant is typically needed. Remember, organics influence the formation of disinfection byproducts and systems will need to comply with the Stage 1 Disinfection Byproduct Rule. A good resource is the EPA guidance manual <i>Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual</i> (May 1999).
pH between 5.5 and 7.5	Optimum pH range for alum. ²
pH between 5.0 and 8.5	Optimum pH range for ferric salts. ²
pH > 8.5	Ferric salts might work or other high acidic coagulants. ³
Temperature < 5°C	Alum and ferric salts may not provide proper floc formation. May want to consider using PACl ¹ or non-sulphated polyhydroxy aluminum chloride. ³

Use of Alum as a Coagulant

- Earliest and most widely used coagulant
- Effective range pH 5.0 to 7.0; (6.5 optimal)
- Effective range for color is ~ 5.5
- Reacts with alkalinity to form floc - results in drop in pH
- For every 2 mg/l Alum; 1 mg/l Lime is added to replace alkalinity; Caustic soda can also be used.



13

Floc Formation

- The positively charged aluminum ions (Al^{+3}) attract the negatively charged particles that cause color and turbidity, thus forming microfloc.



- The positive charged microfloc particles begin to attract and hold more negatively charged particles in the water.
- The microfloc grows into large settable floc due to adsorption and collision of other floc particles

14

Use of Ferrous Sulfate (Copperas) and Lime for Coagulation

- Combination produces Ferric Hydroxide
- pH 8.4 range to 9.0
- Oxygen must added by aeration or chemically such as chlorine
- Very Effective for turbid water
- Care must be taken because color not removed at high pH

15

Use of Ferric Chloride as a Coagulant

- Has wider pH range than Ferrous Sulfate
- Typically used where color removal is also desirable.
- Does not require oxygen supplement

16

Use of Ferric Sulfate as a Coagulant

- Does not require oxygen supplement
- Effective over wider pH ranges
- Effective within all temperature ranges
- Eliminates odors from existing Hydrogen Sulfide
- Lower doses required than Ferrous Sulfate

17

Use of Coagulant Aids

- Lime
- Weighting Agents
- Polymers
 - Cationic +
 - Anionic -
 - Nonionic

18

Coagulant Mixing and Flash Mixers

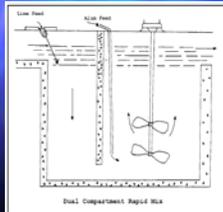
Purpose of the flash mix process is to rapidly mix and equally distribute the coagulant chemical throughout the water.

- Coagulant must make contact with all of the suspended particles.
- Process occurs in seconds.
- First results are formation of very small particles.
- Detention time and the speed of the mixer should be sufficient to thoroughly mix all the chemical with no breakup of floc particles.

19



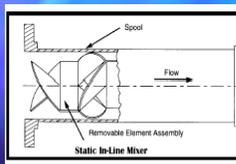
Mixing Coagulants and Coagulant Aids



- Rapid/Flash Mix typically occurs in a tank
- Mixing Devices
 - Mechanical (paddles, turbines, and propellers) are versatile and reliable but use highest amount of energy
 - Diffusers are sensitive to flow changes
 - Pumped blenders – no significant head loss and energy use much less than mechanical
 - Hydraulic uses flow energy in the system
- Mixing velocity 5 – 7 fps
- Coagulant and coagulant aids added in first chamber

20

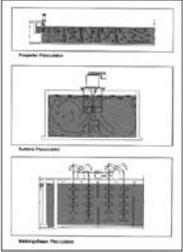
Static Mixer for Polymers



- Used prior to Coagulation
- Addition of oxidizing agents, GAC and polymers
- Used as far as possible upstream to maximize contact time

21

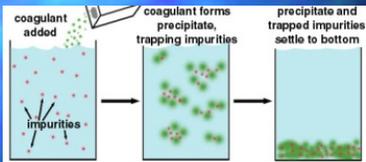
Flocculation Process



- Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles.
- The best flocculation is usually achieved in a compartmentalized basin. Most often three BASINS separated by baffles to prevent SHORT-CIRCUITING.
- Flocculation is controlled by the mixing rate.
- Mixer speed reduced in subsequent tanks to reduce turbulence. This is called tapered-energy mixing.
- Changes in temperature can necessitate longer detention times.

22

Flocculation Followed by Sedimentation



- Instantaneous mix of coagulants
- Neutralizes the negative charges on colloids
- During the gentle mixing of flocculation, allows particles to agglomerate into larger particles
- Heavier particles are removed by settling

23

Importance of Flocculator Speed

- If the speed of the stirring process is too great then the floc particles will be "sheared" or broken apart causing an increase in turbidity.
- If flocculator speed is too slow then "short-circuiting" may occur.
- Purpose is to create a floc of good size (0.1 to 3mm), density, and toughness for later removal in the sedimentation and filtration processes.

24

 **What is Short-Circuiting?**

"A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water."

May result in shorter contact, reaction, or settling times.

25

Desirable Floc Quality

- A popcorn flake is a desirable floc appearance.
- Smooth circular particles tend to settle quicker while irregular shaped particles settle slower.
- Tiny alum floc may be an indication that the chemical dosage is too low.
- If the water has a milky appearance or a bluish tint, the alum dose is probably too high.
- Should be increasing in size as it moves through the basins
- Can be described as discrete and fairly dense in appearance



26

Performance Monitoring

- Mixing needs to be adequate
- Monitor pH for optimum conditions
- Flow measurement is important to accurately establish chemical feed rates, wash water rates, and unit loadings
- Chemical feed systems need dosage control
- Jar Test at the Start of Every Shift or more!

What adjustment should be made in the speed of flocculators when the water temperature drops?

Increase Speed



27

Performance Measurement Using the Jar Test

- A jar test is a lab procedure where varying dosages of coagulant are tested in a series of glass or plastic jars under identical conditions to determine the optimum dosage.
- The jars are injected with coagulant dosages and gently paddled or flocculated to match field conditions as closely as possible.
- After a set of time to simulate field conditions the jars are observed to determine which dosage produces the largest, strongest floc or which dosage produces the floc that settles the fastest.
- Other tests sometimes include a jar test to determine the optimal pH or to determine the turbidity of the settled water and its filterability.

28

Jar Test Apparatus and Procedures

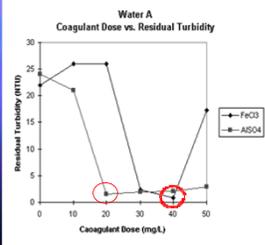


- Six paddles
- One container is control
- RPM gauge allows for mixing speed to match plant conditions

Flash Mix: 1 Minute at 80 RPM
 Flocculation: 30 Minutes at 20 RPM
 Settling: 30 Minutes

29

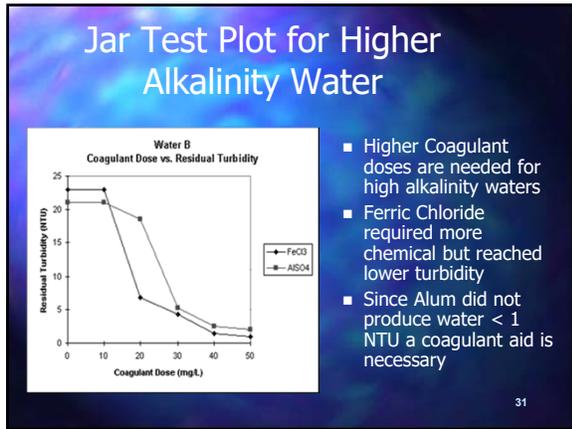
Jar Test Plot for Low Alkalinity Water



Coagulant Dose (mg/L)	FeCl ₃ Residual Turbidity (NTU)	AlSO ₄ Residual Turbidity (NTU)
0	25	25
10	22	25
20	2	25
30	2	25
40	2	2
50	18	18

- Alum initially reacts with low alkalinity
- With Ferric Chloride requires chemical to reach optimal pH before reacting
- Adding too much coagulant increases turbidity

30



Evaluation of Jar Test Results

- Rate of Floc Formation (15 min.)
- Type of Floc Particles (circular or popcorn)
- Clarity of the Water between the Floc
- Size of the Floc (.1 to 3 mm)
- Amount of Floc (too little may need agent)
- Clarity of Water above Settled Floc (clear)
- Volume of Floc

32

