

Coagulation and Flocculation Process Fundamentals

WHY THEY ARE USED

All waters, especially surface waters, contain both dissolved and suspended particles. Coagulation and flocculation processes are used to separate the suspended solids portion from the water.

The suspended particles vary considerably in source, composition charge, particle size, shape, and density. Correct application of coagulation and flocculation processes and selection of the coagulants depend upon understanding the interaction between these factors. The small particles are stabilized (kept in suspension) by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and, since they have the same type of surface charge, repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle out of the water.

HOW THE PROCESSES WORK

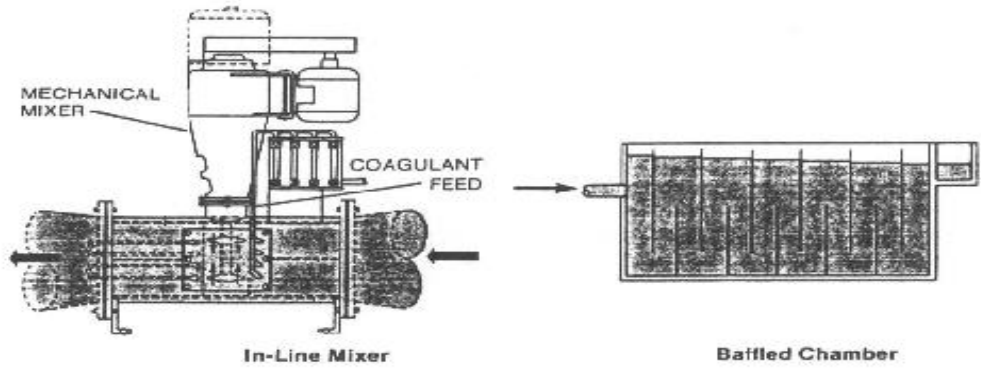
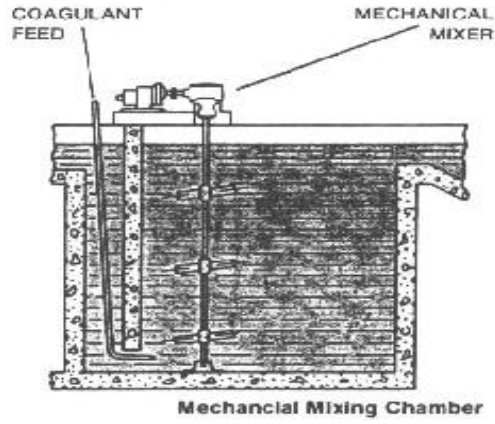
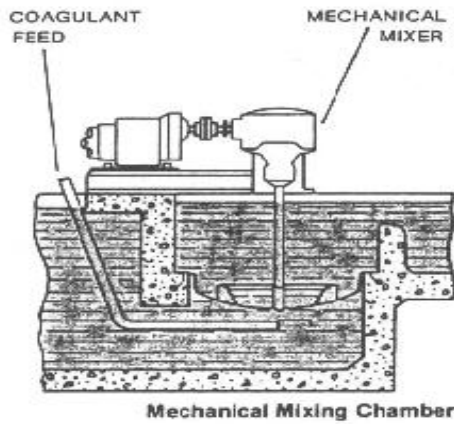
Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc. If step one is incomplete, the following step will be unsuccessful.

COAGULATION

The first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settleable solids such as clay and color-producing organic substances.

Once the charge is neutralized, the small suspended particles are capable of sticking together. The slightly larger particles, formed through this process and called microflocs, are not visible to the naked eye. The water surrounding the newly formed microflocs should be clear. If it is not, all the particles' charges have not been neutralized, and coagulation has not been carried to completion. More coagulant may need to be added.

A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes.

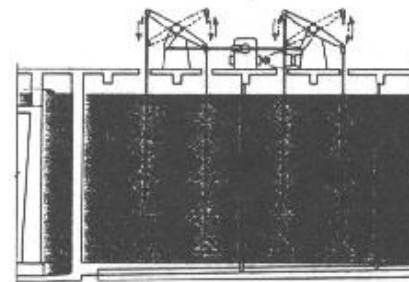
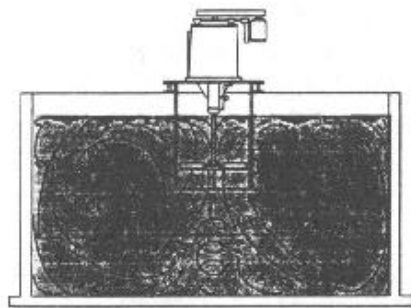
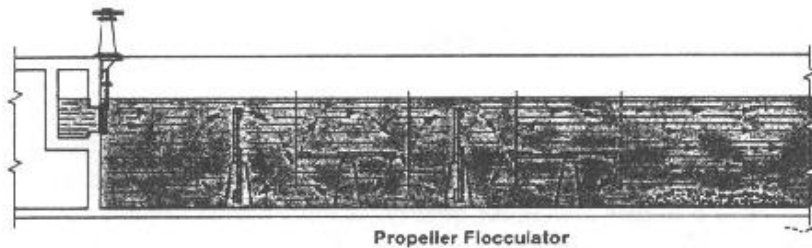


FLOCCULATION

Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles.

The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process.

Design contact times for flocculation range from 15 or 20 minutes to an hour or more.



Operational Considerations

Flocculation requires careful attention to the mixing velocity and amount of mix energy. To prevent the floc from tearing apart or shearing, the mixing velocity and energy input are usually tapered off as the size of the floc increases. Once flocs are torn apart, it is difficult to get them to reform to their optimum size and strength. The amount of operator control available in flocculation is highly dependent upon the type and design of the equipment.

SEDIMENTATION

Design and Operating Considerations

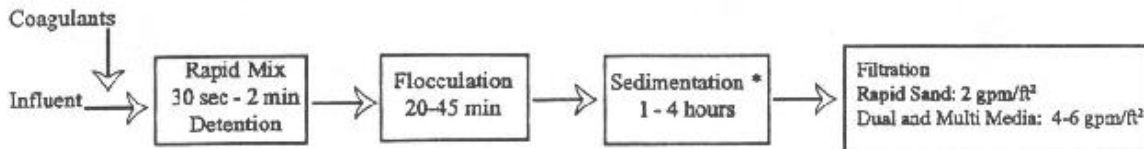
Sedimentation basins are used in conventional plants. Direct-filtration plants skip the sedimentation stage and go directly to filtration. Detention times for sedimentation are in the range of 1 to 4 hours. Inlets are designed to distribute water evenly and at uniform velocities. Overflow rates should not exceed 20,000 gallons per day per foot of weir length. Velocity should not exceed 0.5 feet per minute.

Sedimentation basins are used to settle out the floc before going to the filters. Some type of sludge collection device should be used to remove sludge from the bottom of the basin.

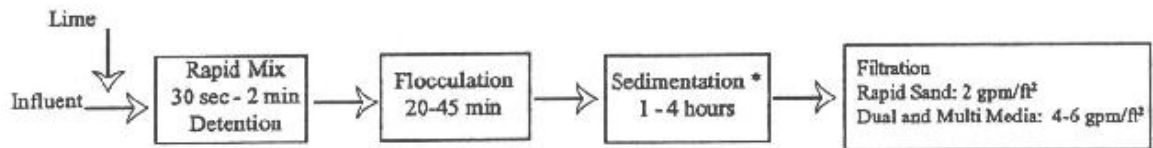
DESIGN CONSIDERATIONS: CONVENTIONAL PLANTS

Conventional plant designs separate the coagulation, or rapid-mix, stage from the flocculation, or slow-mix, stage. Normally this is followed by a sedimentation stage, after which filtration takes place. Plants designed for direct filtration route the water directly from flocculation to filtration. These systems typically have a higher raw-water quality. Conventional designs can incorporate adjustable mixing speeds in both the rapid-mix and slow-mix equipment. Multiple feed points for coagulants, polymers, flocculants, and other chemicals can be provided. There is generally adequate space to separate the feed points for incompatible chemicals.

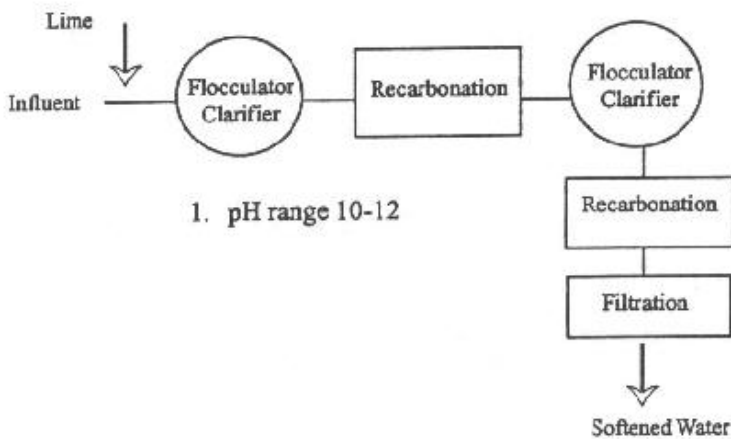
Conventional plant designs have conservative retention times and rise rates. This usually results in requirements for large process basins and a large amount of land for the plant site. On-site pilot plant evaluation of the proposed process, by a qualified engineer familiar with the source of the water, is advisable prior to selection and construction of the units.



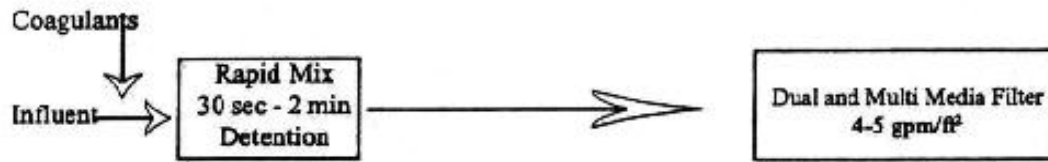
*or alternate solids removal process



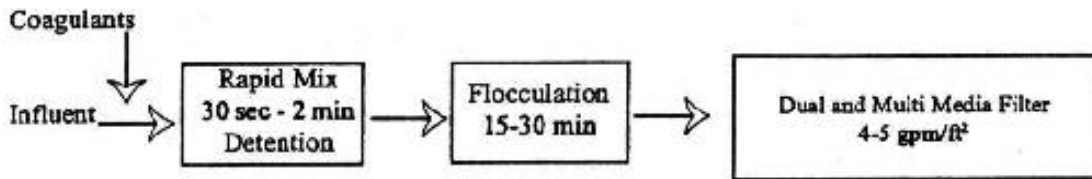
1. pH range 9-10
2. Or alternate solids removal process



1. pH range 10-12



***or alternate solids removal process**



Retention or detention time is the theoretical time in minutes that water spends in a process. It is calculated by dividing the liquid volume, in gallons, of a basin by the plant flow rate in gallons per minute. Actual detention time in a basin will be less than the theoretical detention time because of “dead areas” and short circuiting, which could be due to inadequate baffling.

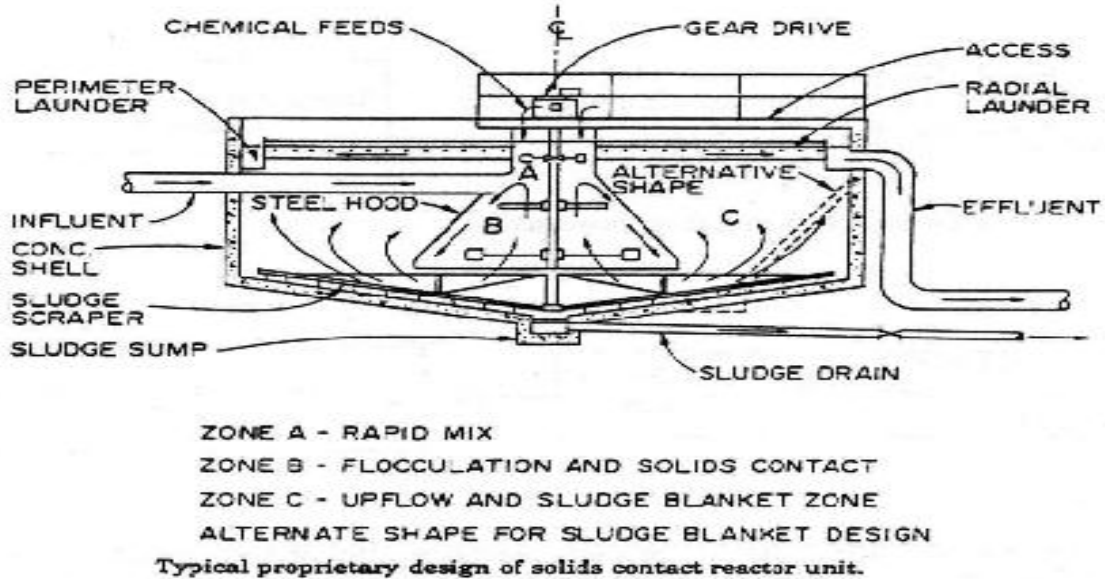
$$\text{Retention time} = \frac{\text{basin volume (gallons)}}{\text{gpm flow}}$$

The rise rate is calculated by dividing the flow in gallons per minute by the net upflow area of the basin in square feet.

$$\text{Rise Rate} = \frac{\text{gpm flow}}{\text{surface area}}$$

DESIGN CONSIDERATIONS: COMBINATION UNITS

Some designs incorporate coagulation, flocculation, and sedimentation within a single unit. These designs can be separated into upflow solids contact units and sludge blanket units. Most solids contact designs use recirculation of previously formed flocs to enhance floc formation and maximize usage of treatment chemicals. Sludge bed designs force the newly forming flocs to pass upward through a suspended bed of floc. In both styles of units, the cross-sectional surface of the basin increases from the bottom to top, causing the water flow to slow as it rises, and allowing the floc to settle out. The combination units generally use higher rise rates and shorter detention time than conventional treatment. Numerous manufacturers market proprietary units based on these design concepts. These units are more compact and require less land for plant site location. On-site pilot plant evaluation of the proposed process, by a qualified engineer familiar with the source water, is advisable prior to selection and construction of combined units.



COAGULANT SELECTION

The choice of coagulant chemical depends upon the nature of the suspended solid to be removed, the raw water conditions, the facility design, and the cost of the amount of chemical necessary to produce the desired result.

Final selection of the coagulant (or coagulants) should be made following thorough jar testing and plant scale evaluation. Considerations must be given to required effluent quality, effect upon down stream treatment process performance, cost, method and cost of sludge handling and disposal, and net overall cost at the dose required for effective treatment.

Inorganic Coagulants

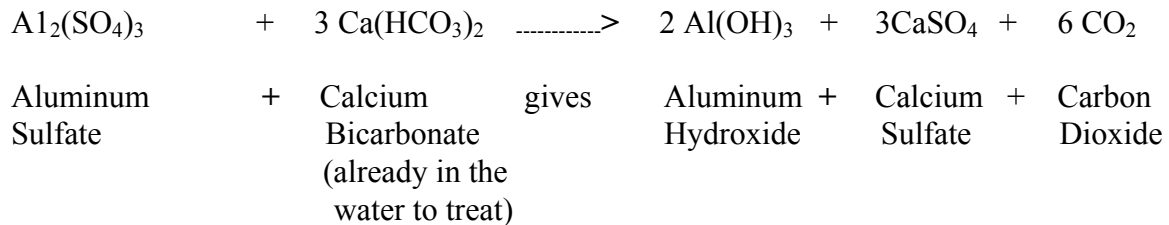
Inorganic coagulants such as aluminum and iron salts are the most commonly used. When added to the water, they furnish highly charged ions to neutralize the suspended particles. The inorganic hydroxides formed produce short polymer chains which enhance microfloc formation.

Inorganic coagulants usually offer the lowest price per pound, are widely available, and, when properly applied, are quite effective in removing most suspended solids. They are also capable of removing a portion of the organic precursors which may combine with chlorine to form disinfection by-products. They produce large volumes of floc which can entrap bacteria as they settle. However, they may alter the pH of the water since they consume alkalinity. When applied in a lime soda ash softening process, alum and iron salts generate demand for lime and soda ash. They require corrosion-resistant storage and feed equipment. The large volumes of settled floc must be disposed of in an environmentally acceptable manner.

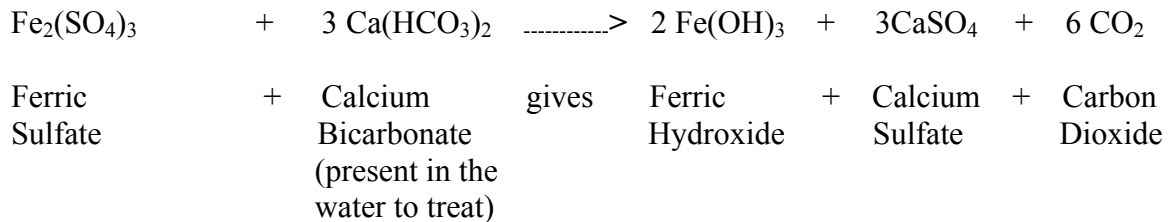
Inorganic Coagulant Reactions

Common coagulant chemicals used are alum, ferric sulfate, ferric chloride, ferrous sulfate, and sodium aluminate. The first four will lower the alkalinity and pH of the solution while the sodium aluminate will add alkalinity and raise the pH. The reactions of each follow:

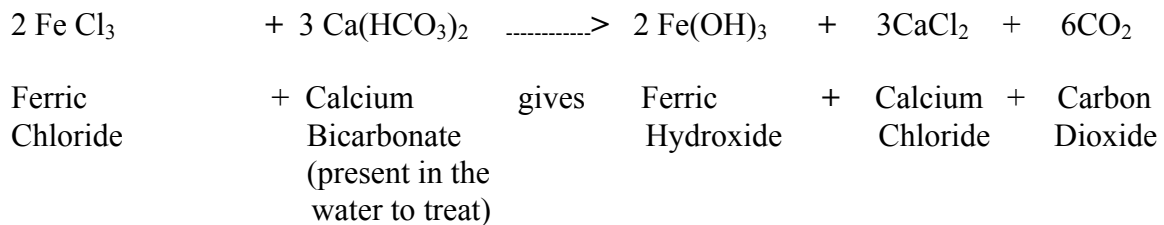
ALUM



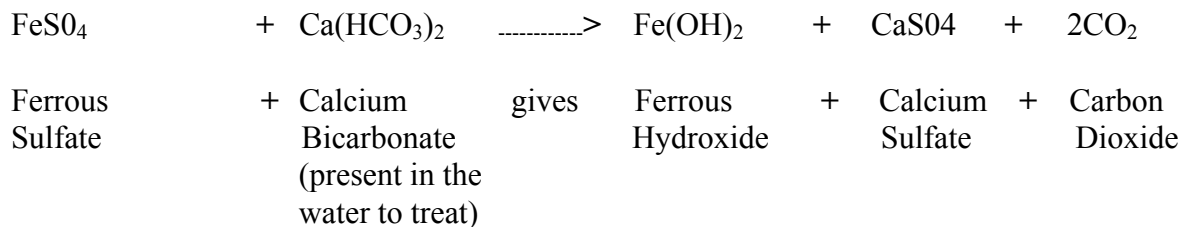
FERRIC SULFATE



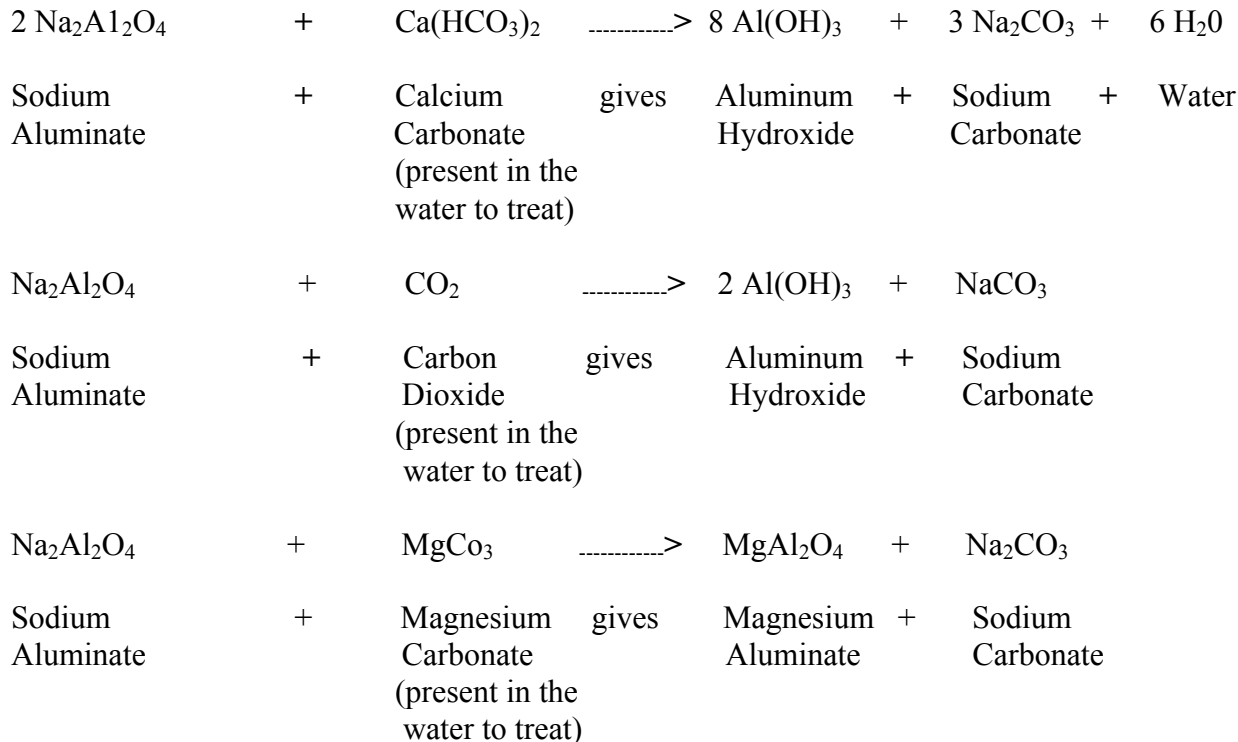
FERRIC CHLORIDE



FERROUS SULFATE



SODIUM ALUMINATE



POLYMERS

Polymers--long-chained, high-molecular-weight, organic chemicals--are becoming more widely used, especially as coagulant aids together with the regular inorganic coagulants. Anionic (negatively charged) polymers are often used with metal coagulants. Low-to-medium weight, positively charged (cationic) polymers may be used alone or in combination with the aluminum and iron type coagulants to attract the suspended solids and neutralize their surface charge. The manufacturer can produce a wide range of products that meet a variety of source-water conditions by controlling the amount and type of charge and relative molecular weight of the polymer.

Polymers are effective over a wider pH range than inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. The floc formed from use of a properly selected polymer will be more resistant to shear, resulting in less carryover and a cleaner effluent.

Polymers are generally several times more expensive in their price per pound than inorganic coagulants. Selection of the proper polymer for the application requires considerable jar testing under simulated plant conditions, followed by pilot or plant-scale trials.

All polymers must be approved for potable water use by regulatory agencies.