Coagulation and Flocculation

Groundwater and surface water contain both dissolved and suspended particles. Coagulation and flocculation are used to separate the suspended solids portion from the water.

Suspended particles vary in source, charge, particle size, shape, and density. Correct application of coagulation and flocculation depends upon these factors. Suspended solids in water have a negative charge and since they have the same type of surface charge, they repel each other when they come close together. Therefore, suspended solids will remain in suspension and will not clump together and settle out of the water, unless proper coagulation and flocculation is used.
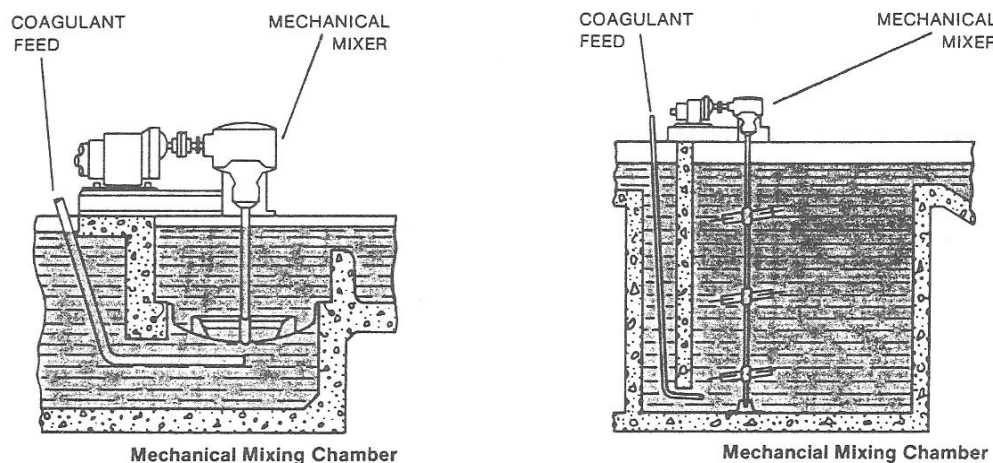
Coagulation and flocculation occurs in successive steps, allowing particle collision and growth of floc. This is then followed by sedimentation (see Sedimentation Chapter). If coagulation is incomplete, flocculation step will be unsuccessful, and if flocculation is incomplete, sedimentation will be unsuccessful.
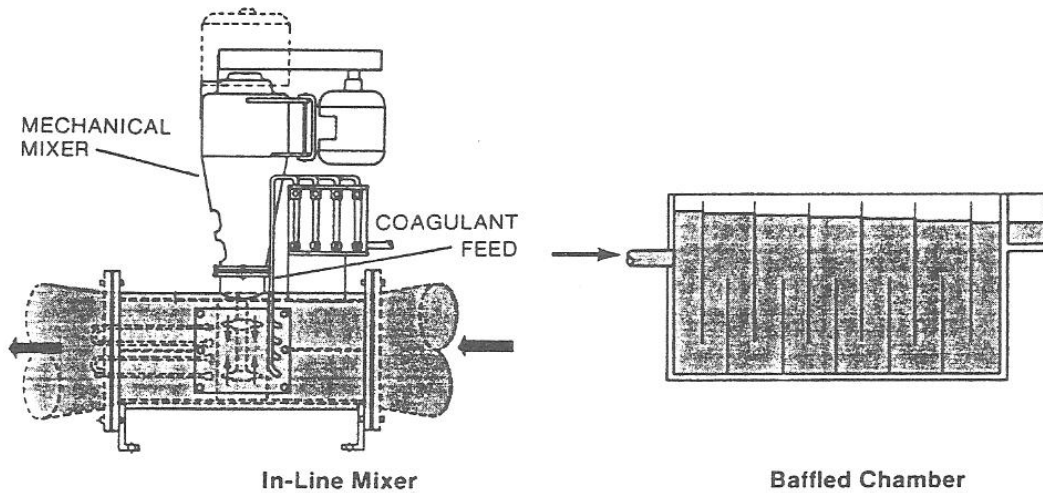
COAGULATION

Coagulant chemicals with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on non-settlable solids (such as clay and color-producing organic substances).

Once the charge is neutralized, the small suspended particles are capable of sticking together. These slightly larger particles are called microflocs, and are not visible to the naked eye. Water surrounding the newly formed microflocs should be clear. If not, coagulation and some of the particles charge have not been neutralized. More coagulant chemicals may need to be added.

A high-energy, rapid-mix to properly disperse 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. Contact time in the rapid-mix chamber is typically 1 to 3 minutes.

Mechanical Mixing Chamber

Mechanical Mixing Chamber

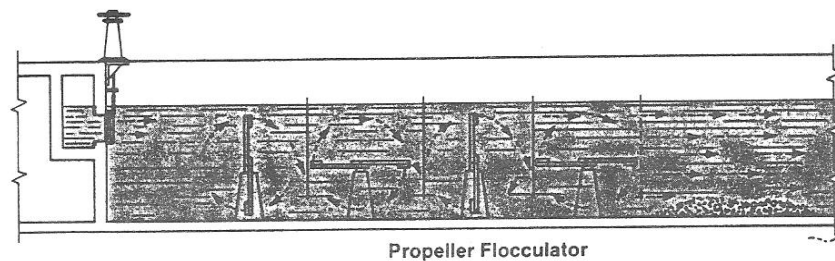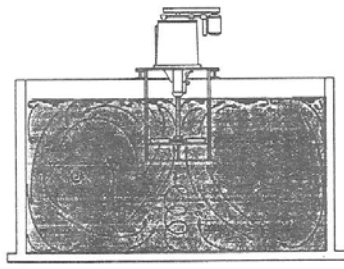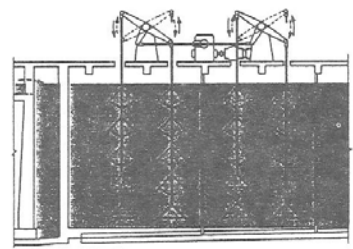In-Line Mixer   Baffled Chamber

FLOCCULATION

Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. Microfloc particles collide, causing them to bond to produce larger, visible flocs called pinflocs. Floc size continues to build with additional collisions and interaction with added inorganic polymers (coagulant) or organic polymers. Macroflocs are formed and high molecular weight polymers, called coagulant aids, may be added to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once floc has reached it optimum size and strength, water is ready for sedimentation.

Design contact times for flocculation range from 15 or 20 minutes to an hour or more, and flocculation requires careful attention to the mixing velocity and amount of mix energy. To prevent floc from tearing apart or shearing, the mixing velocity and energy are usually tapered off as the size of 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.

Propeller Flocculator

Coagulation and Flocculation Process Fundamentals 2
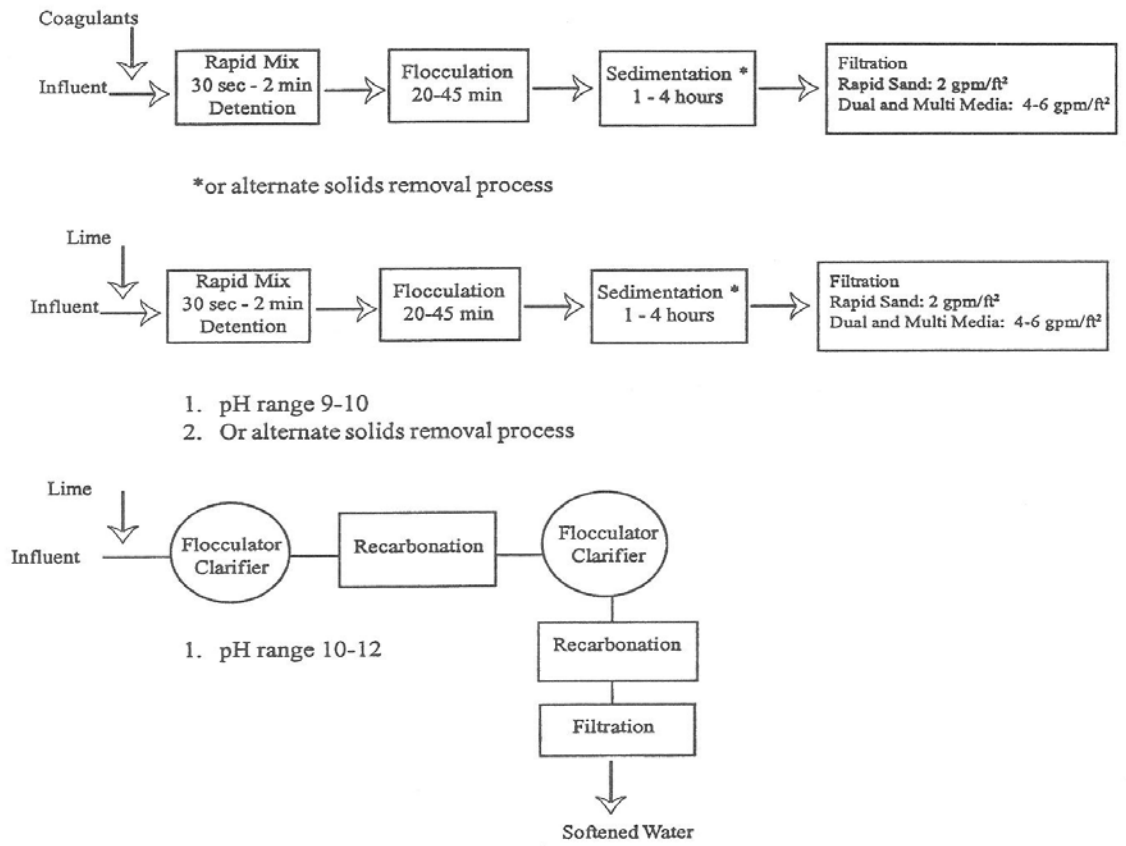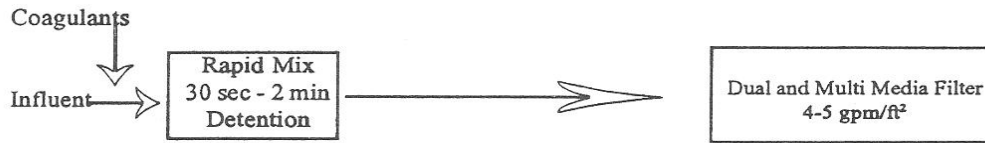
Turbine Flocculator

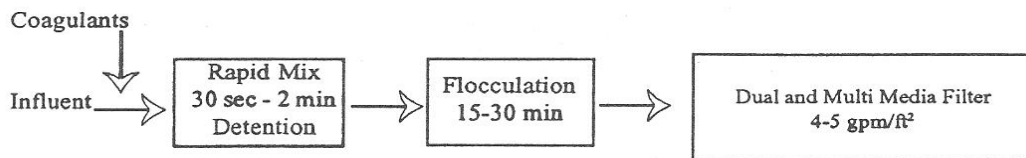

Walking Beam Flocculator

CONVENTIONAL PLANTS

Conventional plants separate coagulation (or rapid-mix) stage from flocculation (or slow-mix) stage. These stages are followed by sedimentation, and then filtration. Plants designed for direct filtration route water directly from flocculation to filtration. These systems typically have a higher raw-water quality. Conventional plants can have 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 and there is generally enough space to separate the feed points for incompatible chemicals.

Conventional plants 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, by a qualified engineer familiar with the water quality, is recommended prior to design.

Coagulants

Influent → Rapid Mix 30 sec - 2 min Detention → Dual and Multi Media Filter 4-5 gpm/ft²

*or alternate solids removal process

Coagulants

Influent → Rapid Mix 30 sec - 2 min Detention → Flocculation 15-30 min → Dual and Multi Media Filter 4-5 gpm/ft²

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

$$\text{Retention time} = \frac{\text{basin volume (gallons)}}{\text{gpm flow}}$$
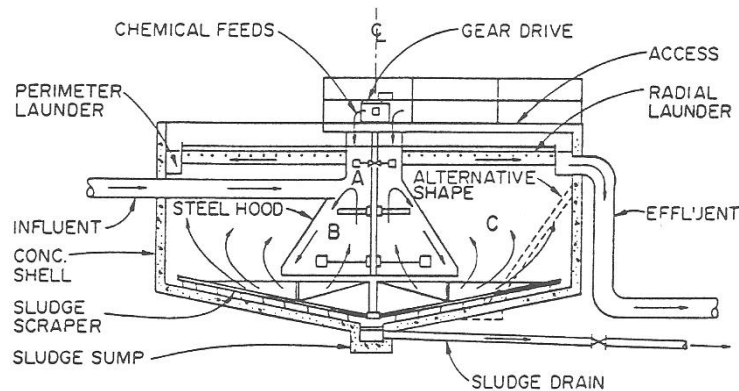
Rise rate is calculated by dividing the flow in gallons per minute by the net water surface area of the basin in square feet.

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

COAGULATION, FLOCCULATION, AND SEDIMENTATION COMBINED

Some designs incorporate coagulation, flocculation, and sedimentation a single unit (either upflow solids contact units or sludge blanket units). Most upflow solids contact units use recirculation of previously formed floes to enhance floc formation and maximize usage of treatment chemicals. Sludge blanket units force 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 bottom to top, causing water flow to slow as it rises, and allowing floc to settle out. 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, by a qualified engineer familiar with the water quality, is recommended prior to design.

ZONE A - RAPID MIX
ZONE B - FLOCCULATION AND SOLIDS CONTACT
ZONE C - UPFLOW AND SLUDGE BLANKET ZONE
ALTERNATE SHAPE FOR SLUDGE BLANKET DESIGN

Typical proprietary design of solids contact reactor unit.

COAGULANT SELECTION

The choice of coagulant chemical depends upon the type of suspended solid to be removed, raw water conditions, facility design, and cost of chemical. Final selection of coagulant (or coagulants) should be made with jar testing and plant scale evaluation. Consideration must be given to required effluent quality, effect upon down stream treatment process performance, cost, method and cost of sludge handling and disposal, and cost of the dose required for effective treatment.

Inorganic Coagulants

Inorganic coagulants such as aluminum and iron salts are the most commonly used. When added to water, these highly charged ions to neutralize the suspended particles. The inorganic hydroxides that are 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 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. Inorganic coagulants produce large volumes of floc which can also entrap bacteria as they settle.

Inorganic coagulants 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 also require corrosion-resistant storage and feed equipment. It is important to note that large volumes of settled floc must be disposed of in an environmentally acceptable manner.

Alum, ferric sulfate, and ferric chloride, lower the alkalinity, and pH reactions for each follow:
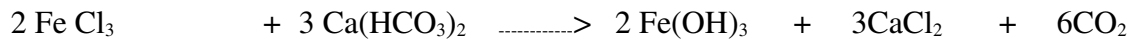
Alum

$$Al_2(SO_4)_3 \quad + \quad 3\,Ca(HCO_3)_2 \quad \text{----->} \quad 2\,Al(OH)_3 \quad + \quad 3CaSO_4 \quad + \quad 6\,CO_2$$

| Aluminum Sulfate | + | Calcium Bicarbonate (present in the water to treat) | gives | Aluminum Hydroxide | + | Calcium Sulfate | + | Carbon Dioxide |

Ferric Sulfate

$$Fe_2(SO_4)_3 \quad + \quad 3\,Ca(HCO_3)_2 \quad \text{----->} \quad 2\,Fe(OH)_3 \quad + \quad 3CaSO_4 \quad + \quad 6\,CO_2$$

| Ferric Sulfate | + | Calcium Bicarbonate (present in the water to treat) | gives | Ferric Hydroxide | + | Calcium Sulfate | + | Carbon Dioxide |

Ferric Chloride

$$2\,Fe\,Cl_3 \quad + \quad 3\,Ca(HCO_3)_2 \quad \text{----->} \quad 2\,Fe(OH)_3 \quad + \quad 3CaCl_2 \quad + \quad 6CO_2$$

| Ferric Chloride | + | Calcium Bicarbonate (present in the water to treat) | gives | Ferric Hydroxide | + | Calcium Chloride | + | Carbon Dioxide |

Polymers

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

Polymers are effective over a wider pH range than inorganic coagulants. They can be applied at lower doses, and do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. 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 price per pound than inorganic coagulants. Selection of the proper polymer requires considerable jar testing under simulated plant conditions, followed by pilot or plant-scale trials. All polymers must also be approved for potable water use by regulatory agencies.