1.1: Chemical Feed Calculations In Water Treatment Processes

Learning Objectives

- Calculate applied feed dosage rates
- Calculate flow rates
- Calculate applied feed dosage rates in pounds per day

Water Treatment Objectives

The basic objective in the operation of drinking water treatment plants is to produce drinking water that is safe and aesthetically pleasing at a reasonable cost with respect to capital as well as operation and maintenance.
From a public health perspective, the production of safe drinking water is one that is free of harmful microorganisms and toxic materials, and this object is the first priority. It is also important to produce high-quality water that appeals to the consumer. Generally, the water must be clear, free of turbidity, colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that do not stain plumbing fixtures and clothes, do not corrode plumbing fixtures and piping, and do not leave scale deposits or spot glassware.

Consumer sensitivity to the environment has significantly increased in recent years. With regard to water quality, consumer demands have never been greater. In some instances, consumers have substituted bottled water to meet specific needs, namely, for drinking water and cooking purposes.

Design engineers select water treatment processes on the basis of the type of water source, source water quality, and the desired finished water quality which is established by drinking water regulations and consumer desires.

Water has many important uses and each requires a specific level of water quality. Delivering safe and pleasant drinking water to customers should be the operator's primary concern. Drinking water should be acceptable to domestic and commercial water users. Some industries, such as food and drug processors and the electronics industry, require high-quality water. Many industries locate where the local water supply meets their specific needs, and other industries maintain a water treatment facility on-site to produce water suitable for their needs.

The Safe Drinking Water Act

Regulations concerning public water systems are focused on the production of water that is safe for people to drink.
These regulations continue to change in order to address new information concerning the health effects of different substances that may be in drinking water. Operators are urged to develop close working relationships with local regulatory agencies in order to keep informed of the changes in regulations and requirements. An excellent source of up-to-the-minute information concerning drinking water regulations is the US Environmental Protection Agency's toll-free Safe Drinking Water Hotline at (800)426-4791.

In 1974, the Safe Drinking Water Act was signed into law, giving the federal government, through the EPA, the authority to:

- Set national standards regulating the levels of contaminants in drinking water
- Require public water systems to monitor and report their levels of identified contaminants
- Establish uniform guidelines specifying the acceptable treatment technologies for cleansing drinking water of unsafe levels of pollutants

The EPA sets two kinds of drinking water standards. Primary regulations establish maximum contaminant levels based on the health significance of the contaminants while the secondary standards are established based on aesthetic considerations and are a state option.

While the Safe Drinking Water Act (SDWA) gives the EPA responsibility for developing drinking water regulations, it gives state regulatory agencies the opportunity to assume primary responsibility for enforcing the regulations.

Implementation of the SDWA has improved basic drinking water purity across the nation. However, the EPA surveys of surface water and groundwater indicate the presence of synthetic organic chemicals in the nation's water sources, with a small percentage at the levels of concern. In addition, research studies suggest that some naturally occurring contaminants may pose even greater risks to human health than synthetic contaminants. Further, the concern is growing concerning microbial and radon contamination.

In the years following the passage of the SDWA, Congress felt that the EPA was slow to regulate contaminants and states were lax in enforcing the law. Consequently, in 1986 and again in 1996, Congress enacted amendments designed to strengthen the 1974 SDWA. The amendments set deadlines for the establishment of maximum contaminant levels, placed greater emphasis on enforcement, authorized penalties for tampering with drinking water supplies, mandated the complete elimination of lead from drinking water, and placed considerable emphasis on the protection of underground drinking water sources.

In 1996, the president signed new SDWA amendments into law. These amendments changed the existing SDWA, created new programs, and included more than $12-billion in federal funds for drinking water programs and activities.

Topics covered in the amendments include:

- Arsenic research
- Assistance for water infrastructure and watersheds
- Assistance to low-income communities located along the US Mexican border
- Backwash water recycling
- Bottled water
- Capacity development

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Because not all contaminants can be controlled through treatment processes, source protection is an important component of producing high-quality drinking water.

Water Treatment Plants

Communities have established water treatment plants to produce safe and pleasant drinking water that meets SWDA requirements. This water must be free of disease-causing organisms and toxic substances. Also, the water should not
have a disagreeable taste, odor, or appearance.

A water treatment plant takes raw water from a source, such as a stream or a lake, groundwater, or reclaimed water, and passes the water through a series of interrelated treatment processes; if the quality of the raw water changes or any process fails to do its intended job, the downstream processes are affected. The raw water flows through tanks or basins where chemicals are added and mixed with it. Then the water slowly flows through larger tanks that allow the heavier suspended solids to settle out. Any remaining solids are removed by filtration and the water is disinfected. The size of a water treatment plant as well as the number and specific types of processes it uses depends on several factors:

- Raw water impurities
- Water quality standards
- Water demand by population served
- Fire protection
- Cost considerations

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Figure \(\PageIndex{2}\): [Image](https://workforce.libretexts.org/Bookshelves/Water_Systems_Technology/Water_151%3A_Water_Treatment_Plant_and_Ope…)

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## Treatment Process Changes

To maintain adequate clear well and distribution system water storage levels, raw or source water flow changes may be required. Raw water flow changes should take into account the travel or detention time between the source of supply and the treatment plant.
When storage demands change and require adjustments in the flow of water through a plant, the operator may also be required to perform the following functions:

- Adjust chemical feed rates
- Change filtration rates
- Perform jar tests
- Observe floc formation and floc settling characteristics
- Monitor process performance
- Collect process water quality samples
- Visually inspect overall process conditions

Some of these changes may occur automatically if the plant has flow-paced chemical feeders. However, changes in chemical feed rates are required when using manually operated chemical feeders because they are generally set to feed a specific amount of chemical, and this amount is dependent on the rate of flow.

Filters are usually operated at a constant production rate. Automatic control systems typically maintain uniform flow rates, but the number of filters in service can be changed by starting or stopping individual filter units to meet changing needs.

The unit treatment processes, such as coagulation, flocculation, and sedimentation, are designed to operate over a broad range of flow rates. However, in some instances, major flow changes may require adding or removing treatment processes from service.

### Chemical Use and Handling

A wide variety of chemicals are used in water treatment plants in the production of safe and palatable drinking water. They play a crucial role in controlling process performance and producing high-quality water. Chemicals are used in the following aspects of water treatment:

- Clarification (turbidity reduction)
- Disinfection
- Taste and odor control
- Algae control
- Corrosion/scaling control
- Water softening
- Fluoridation

The American Water Works Association (AWWA) has developed standards for many of the chemicals, which help to ensure that only quality chemicals are used in water treatment. These standards should be referred to when ordering treatment chemicals (see AWWAQ Standards, Section B-Treatment, [www.awwa.org](http://www.awwa.org)).

The initial selection of specific chemicals and anticipated feed rates for a given application are frequently determined by pilot-plant testing of the specific source water. Pilot-plant tests are usually performed by the water treatment plant
designer by constructing a small scale treatment plant at or near the source of supply. Pilot tests provide the designer, as well as the treatment plant operator, with valuable information on the treatability of a given source of supply over a broad range of water quality conditions.

Operators should be thoroughly familiar with the types of chemicals used in water treatment, specific chemical selection and applications, evaluation methods for determining performance, and safe storage and handling techniques. All chemicals are potentially dangerous, and all necessary precautions must be taken before handling any chemical. All containers, no matter what the use, should bear precautionary labeling.

A Safety Data Sheet (SDS) is the best source of information concerning dangerous chemicals. No chemical should be received, stored, or handled until essential safety information is provided to those individuals who will come into contact with the substance. Among other informational items, the SDS will provide:

- Identification of the product and the manufacturer or distributor
- Identification of all hazards regarding the chemical
- Composition/information on ingredients
- First-aid measures including important symptoms/effects and required treatment
- Fire-fighting measures including suitable extinguishing techniques and equipment and chemical hazards from fire
- Accidental release measures listing emergency procedures, protective equipment, and proper methods of containment and cleanup
- Handling and storage precautions, including incompatibilities
- Exposure controls/personal protection including exposure and threshold limits and personal protective equipment
- Stability and reactivity, including possible hazardous reactions
- Toxic effects on living organisms including routes of exposure, as well as related symptoms, acute and chronic effects, and numerical measures of toxicity

Remember, do not work with a chemical unless the hazards involved with its usage are understood and unless the necessary protective equipment is available. Contact local safety regulatory agencies concerning specific chemicals if any doubt exists concerning safe procedures.

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**Coagulation and Flocculation**

Particulate impurities in water result from land erosion, dissolved minerals, and the decay of plant material. Additional impurities are added by airborne contamination, industrial discharges, and animal wastes. Surface water sources and reclaimed water, polluted by people and nature, are likely to contain suspended and dissolved organic and inorganic material, as well as biological forms such as bacteria and plankton. With few exceptions, this water requires treatment to remove particulate impurities and color before it is distributed to the consumer.
Coagulation

The term coagulation describes the effect produced when certain chemicals are added to raw water containing slowly settling or nonsettleable particles. The small particles begin to form larger or heavier floc, which is removed by sedimentation and filtration.

The mixing of the coagulant chemical and the raw water to be treated is commonly referred to as flash mixing. The primary purpose of the flash-mix process is to rapidly mix and equally distribute the coagulant chemical throughout the water column. The entire process occurs in a very short time (several seconds), and the first results are the formation of very small particles.

Coagulants

In practice, chemical coagulants are referred to as primary coagulants or as coagulant aids. Primary coagulants neutralize the electrical charges of the particles, which cause them to begin to clump together. The purpose of coagulant aids is to add density to slow-settling flocs and add toughness so the floc will not break up in the processes that follow.

Metallic salts like aluminum sulfate, ferric sulfate, ferrous sulfate, and synthetic organic polymers are commonly used as coagulation chemicals in water treatment because they are effective, relatively low in cost, available, and easy to handle, store, and apply.

When metallic salts, such as aluminum sulfate or ferric sulfate, are added to water, a series of reactions occur with the water and with other ions in the water. Sufficient chemical quantities must be added to the water to exceed the solubility limit of the metal hydroxide, resulting in the formation of a precipitate (floc). The resulting floc formed will then adsorb on particles (turbidity) in the water.
The synthetic organic polymers used in water treatment consist of long chains of small subunits, called monomers (which is a molecule group). The polymer chains can be linear or branched structures, ranging in length from a fraction of a micron to 10 microns. The total number of monomers in a synthetic polymer can be varied to produce materials of different molecular weights, which vary from about 100 to 10,000,000. Cationic polymers have a positive electrical charge, anionic polymers have a negative charge, and nonionic polymers have no electrical charge.

The polymers normally used in water treatment contain ionizable groups on the monomeric units and are referred to as polyelectrolytes. Polymers with positively charged groups on the monomeric units are referred to as cationic polyelectrolytes, while polymers with negatively charged particles are called anionic polyelectrolytes. Polymers without ionizable groups are referred to as nonionic polymers.

Cationic polymers have the ability to adsorb on negatively charged particles, turbidity, and neutralize their charge. They can also form an interparticle bridge that collects the particles. Anionic and nonionic polymers also form interparticle bridges, which aid in collecting and removing particles from water.

While alum is perhaps the most commonly used coagulant chemical, cationic polymers are used in the water treatment field as a primary coagulant and as a coagulant aid. Anionic and nonionic polymers have also proven to be effective in certain applications as coagulant aids and filter aids.

One of the problems that will confront the water treatment plant operator in the selection of an appropriate polymer is that a tremendous number of polymers are available in the marketplace, and no universal evaluation method has been adopted for polymer selection. The operator should use caution in the selection and use of polymers and should take note of these considerations:

- Polymer overdosing will adversely affect coagulation efficiency and when used as a filter aid, overdosing can result in accelerated head loss buildup.
- Not all water supplies can be treated with equal success.
- Some polymers lose their effectiveness when used in the presence of a chlorine residual.
- Some polymers are dosage limited. The operator should obtain the maximum safe dosage that can be applied from the specific chemical manufacturer.

Because universal standards do not exist for the selection and use of organic polymers, the operator should be careful to select those products that have been approved by state and federal regulatory agencies for use in potable water treatment. The chemical supplier should be required to provide written evidence of this approval. Many chemical suppliers have considerable experience in dealing with many types of water and may be able to recommend the best polymer for the situation.

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Basic Coagulant Chemistry

The theory of coagulation is complex. 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.

For a specific coagulant, the pH of the water determines which hydrolysis species predominates after mixing the chemical with the water to be treated. Lower pH values tend to favor positively charged species, which are desirable for
reacting with negatively charged colloids and particulates, forming insoluble flocs, and removing impurities from the water.

The best pH for coagulation usually falls in the range of pH 5 to 7. The proper pH range must be maintained because coagulants generally react with the alkalinity in the water. Residual alkalinity in the water serves as a buffer to the system preventing the pH from changing, and alkalinity aids in the complete precipitation of the coagulant chemicals. The amount of alkalinity in the source water is generally not a problem unless the alkalinity is very low. Alkalinity may be increased by the addition of lime or soda ash.

Polymers are generally added in the coagulation process to stimulate or improve the formation of insoluble flocs.

Generally, the operator has no control over the pH and alkalinity of the source water. Hence, evaluation of these water quality indicators may play a major role in selecting the type of chemical coagulants to be used at a particular water treatment plant, or in changing the type of coagulant normally used if significant changes in pH and alkalinity occur in the raw water.

In some instances, the natural alkalinity in the raw water may be too low to produce complete precipitation of alum. In these cases, lime is often added to ensure complete precipitation. Care must be used to keep the pH within the desired range.

Overdosing as well as under-dosing of coagulants can lead to reduced solids removal efficiency. This condition can be corrected by carefully performing jar tests and verifying process performance after making any changes in the operation of the coagulation process.

**Effective Mixing**

It is desirable to complete the coagulation reaction, mixing of chemicals into the water, in as short of a time as possible. It is preferable to complete the mixing in several seconds because the reaction time is short. For complete coagulation and flocculation to take place, the coagulant must make contact with the suspended particles in the water. This process is accomplished by flash mixing.

Several methods can be used to mix the chemicals with the water to be treated:

- Hydraulic mixing using flow energy in the system
- Mechanical mixing
- Diffusers and grid systems
- Pumped blenders

Hydraulic mixing with baffles or throttling valves works well in systems that have sufficient water velocity to cause turbulence in the water being treated. The turbulence in the flowing water mixes the chemicals with the water.

Mechanical mixers like paddles, turbines, and propellers are frequently used in coagulation facilities. Mechanical mixers are versatile and reliable; however, they use the greatest amount of electric energy for mixing the coagulant with the water being treated.
Pumped blenders have also been used for mixing in coagulation facilities. In this system, the coagulant is added directly to the water being treated through a diffuser in a pipe. This system can provide rapid dispersion of the coagulant and does not create any significant head loss in the system. Electric energy consumption is considerably less than that of a comparable mechanical mixer.

Mixing of chemical coagulants can be satisfactorily accomplished in a coagulation basin, a special rectangular tank with mixing devices. Mixing may also occur in the influent channel or a pipeline to the flocculation basin if the flow velocity is high enough to produce the necessary turbulence. The shape of the basin is part of the flash-mixing system design as well.

**Flocculation**

Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles. The flocculation process provides contact between particles to promote their gathering together into floc for ease of removal by sedimentation and filtration. Generally, these contacts or collisions between particles result from gentile stirring created by a mechanical or hydraulic means of mixing.

An efficient flocculation process involves the selection of the right stirring time, detention time, the proper stirring intensity, a properly shaped basin for uniform mixing, and mechanical equipment or other means of creating the stirring action. Insufficient mixing will result in ineffective collisions and poor floc formation. Excessive mixing may tear apart the flocculated particles after they have clumped together.

**Detention Time**

Detention time is usually not a critical factor in the coagulation or flash mixing process if the chemical coagulants are satisfactorily dispersed into the water being treated and mixed for at least several seconds. Detention time is required for the necessary chemical reactions to take place. Some operators have been able to reduce coagulant dosages by increasing the amount of detention time between the point of the addition of the coagulant and the flocculation basins. In the flocculation process, however, stirring, or detention, time is quite important. The minimum detention time recommended for flocculation ranges from about 5 to 20 minutes for direct filtration systems and up to 30 minutes for conventional filtration. Also, the size and shape of the flocculation facility influence the detention time needed for optimum floc development.

**Types of Flocculators**

Two types of mechanical flocculators are commonly installed, horizontal paddle wheels and vertical flocculators. They provide satisfactory performance; however, the vertical flocculators usually require less maintenance because they eliminate submerged bearings and packing. Vertical flocculators can be of the propeller, paddle, or turbines types.

Some flocculation can also be accomplished by the turbulence resulting from the roughness in conduits or channels, or by the dissipated energy for head losses associated with weirs, baffles, and orifices used to create turbulence, which will mix chemicals with the water. Weirs and baffles are boards or plates that water flows over while orifices are holes in walls that water flows through. Generally, these methods find only limited use because of the disadvantages attributed to
a localized distribution of turbulence, inadequate detention time, and widely variable turbulence resulting from flow fluctuations.

**Flocculation Basins**

The shapes of flocculation basins are determined partially by the flocculator selected and for the basin’s compatibility with adjoining structures like sedimentation basins. Flocculation basins for horizontal flocculators are generally rectangular in shape, while basins for vertical flocculators are nearly square. The depth of flocculation basins is usually about the same as the sedimentation basins.

The best flocculation is usually achieved in a compartmentalized basin. The compartments are separated by baffles to prevent short-circuiting of the water being treated. The turbulence can be reduced gradually by reducing the speed of the mixers in each succeeding tank or by reducing the surface area of the paddles. This design is called tapered energy mixing. The reason for reducing the speed of the stirrers is to prevent breaking apart the large floc particles that have already formed. If the floc is broken up, then the resulting floc will not settle and will overload the filters.

The solids-contact process, upflow clarifiers, is used in some water treatment plants to improve the overall solids removal process. These units combine the coagulation, flocculation, and sedimentation processes.

**Interaction with Other Treatment Processes**

Coagulation and flocculation processes are required to precondition or prepare nonsettleable particles present in raw water for removal by sedimentation and filtration. Small particles, without proper coagulation and flocculation, are too light to settle out of the water column and will not be large enough to be trapped during filtration. It is convenient to consider coagulation-flocculation as one treatment process.

Because the purpose of coagulation-flocculation is to promote particulate removal, the effectiveness of the sedimentation and filtration processes, as well as overall plant performance, depends upon successful coagulation-flocculation. Disinfection of the water can also be affected by poor coagulation-flocculation performance. Bacteria and other disease-causing organisms can be bound up in suspended particles; and thereby, shielded from disinfection. If the solids removal processes are inadequate before final disinfection, especially filtration, then turbidity and disinfection will be inadequate. Effective coagulation-flocculation promotes the removal of natural organic compounds. Removal of these compounds reduces the formation of trihalomethanes following the use of chlorine for disinfection.

**Process Control for Coagulation/Flocculation**

The theory behind the chemical reactions and the formation of floc associated with the coagulation-flocculation process is complex. From a practical viewpoint, the operator of the water treatment plant must be able to measure and control the performance of these processes on a continuous basis.

The most important consideration in coagulation-flocculation process control is the selection of the proper type and amount of coagulant chemicals to be added to the water being treated. This determination is commonly made in the laboratory with the aid of a jar testing apparatus. When selecting a particular type of coagulant chemical, consideration
must be given to the quantity and solids content of the sludge created and the means of ultimate disposal. Jar tests should be run at least daily and more often when the quality of the raw water changes. Changes in the raw water may require changes in the amount of chemical or type of chemical.

### Normal Operation

Coagulation-flocculation is a pretreatment process for the sedimentation and filtration processes. The suspended solids are mostly removed in the sedimentation basin; and, filtration is the final step in the process of removing solids from the water. The coagulation-flocculation process should be operated and controlled to improve filtration and produce filtered final water that is low in turbidity.

The measurement of filtered water turbidity periodically using grab samples or continuously using a turbidity meter will give the operator a good indication of the overall process performance. However, the operator cannot rely solely on filtered water turbidity for complete process control. The difficulty in relying on a single water quality indicator, such as turbidity, is that it takes a considerable amount of time to transport the water through the various treatment processes before it is filtered and turbidity measured. Depending on the amount of water being processed, the total transit time through the treatment plant can vary from as few as 2 hours to more than 6 hours. This amount of time means that a change in coagulant dosage at the front end of the plant will not be noticed in the final finished water quality for at least 2 hours, depending on flow conditions. Turbidity, as well as other water quality indicators, such as pH, temperature, chlorine demand, and floc quality, must be monitored throughout the water treatment process so that poor process performance can be spotted early and corrective measures can be taken.

Process control guidelines for a specific plant are often developed to assist the operator in making these determinations. These guidelines incorporate theory, operator experience, practical knowledge of the source water conditions, and known performance characteristics of the treatment facility.

### Process Actions

In the normal operation of the coagulation-flocculation process, the operator performs a variety of jobs within the water treatment plant. The number and types of functions that each operator will perform vary considerably depending on the size and type of plant and the number of operators working at the plant. In some facilities, operators are required to control almost all process actions as well as perform most routine maintenance activities. Regardless of the plant size, operators should be thoroughly familiar with the routine and special operations and maintenance procedures associated with the plant’s treatment processes.

Jobs performed by an operator in the normal operation of the coagulation-flocculation process include:

- Monitor process performance
- Evaluate water quality conditions (raw and treated water)
- Check and adjust process controls and equipment
- Visually inspect facilities

Monitoring process performance is an ongoing activity. Filtered water turbidity levels are controlled to a great extent by the efficiency of the coagulation-flocculation process. Early detection of a failure is extremely important because
considerable time elapses while the water flows through the coagulation, flocculation, sedimentation, and filtration processes.

Process performance can be monitored with the aid of continuous water quality analyzers, which automatically measure a specific water quality indicator such as turbidity. However, reliable and accurate water quality analyzers are expensive and, in certain cases, automated equipment is not readily available for measuring water quality indicators of concern to operators. A combination of techniques must be used by operators to evaluate process performance including visual observations, and periodic laboratory tests to supplement continuous water quality analyzers.

Visual observations and laboratory tests of coagulation-flocculation process performance should be performed on a routine basis. The most common laboratory tests are turbidity, alkalinity, pH, color, temperature, and chlorine demand. The frequency of these observations and tests depends on how much the quality of the source water supply can or does change. In treatment plants where the source water is stored in a large upstream lake or reservoir, the water quality is generally more stable or constant than water taken directly from rivers or streams.

In the case of direct diversions from a stream or river, water quality conditions will vary seasonally as well as daily. In extreme cases, such as during heavy runoff periods, hourly changes in water quality can be expected. The appropriate frequency of performing certain tests may be as often as hourly, or perhaps once per 8-hour shift.

Visual checks of the coagulation-flocculation process generally include an observation of the turbulence of the water in the flash-mixing channel, or chamber, and close observation of the size and distribution of floc in the flocculation basins. Uneven distribution of floc could be an indication of short-circuiting in the flocculation basin. Floc particles that are too small or too large may not settle properly and could cause trouble during removal in the sedimentation and filtration processes. These observations are frequently supplemented by laboratory evaluations, which are necessary to provide better data.

Floc settling characteristics require laboratory evaluation based on trial and experience methods using jar testing. The speed adjustment of flocculators take into account:

- The volume of floc to be formed, such as if source water turbidity is low, a small pinpoint floc may be best suited for removal on the filters in direct filtration. Lower flocculator speeds are appropriate in this case. On the other hand, high turbidity source water generally requires near-maximum flocculator speed to produce a readily settleable floc.
- Visual observations of short-circuiting may indicate flocculator mixing intensity is not sufficient, while floc breakup is an indication that the mixing turbulence is too high for the type of floc formed.
- Water temperature affects the rate of chemical reactions. These reactions decrease with temperature so that increasing the speed of the flocculator to account for lower water temperatures because higher mixing turbulence is required.

These concepts are not easily measured. Experience and judgment are needed. One of the real limitations in process control is too much reliance on the settled turbidity value. Turbidity gives an indirect measurement of suspended solids concentration, it does not describe particle size, density, volume, or the ability of a particular filter to handle the water being applied to it.

Based on an overall evaluation of process performance, the operator may need to make minor changes in chemical feed dosages or adjust the speed of the flash mixer or flocculators. These processes are normal actions associated with minor changes in source water quality such as turbidity or temperature fluctuations.
Flash mixers are generally less sensitive to speed adjustments than flocculators because their primary purpose is to disperse chemicals rapidly into the water being treated. This reaction is almost instantaneous.

Process equipment, such as chemical feeders, should be checked regularly to ensure that they are accurately feeding the desired amount of chemical.

The operator should routinely perform a visual inspection of the overall coagulation-flocculation physical facilities. This inspection is part of good housekeeping practices. Leaves, twigs, and other debris can easily buildup in influent channels or in flocculation basins. If ignored, this material can get into other processes where it can foul meters, water quality monitors, pumps, or other mechanical equipment. In some cases, taste and odor problems can develop from microorganisms that can grow in debris and sediment that accumulate in plant facilities.

**Detention Times**

To calculate the expected detention times in the flash-mix chamber, distribution channel, and flocculation basins, use the dimensions of the basin or pipe to calculate the volume in gallons and divide this volume in gallons by the flow. The calculation will be in the units of time that are used for the flow. These times are important when determining the optimum chemical dosage for the water that is being treated using jar tests. Also, these times are necessary for the desired chemical reactions to occur.

**Formulas**

- To calculate the volume (V) of a rectangular tank or basin in cubic feet:
  \[ V, \text{ ft}^3 = \text{Length, ft} \times \text{Width, ft} \times \text{Depth, ft} \]
- To calculate the volume of a circular tank or clarifier in cubic feet:
  \[ V, \text{ ft}^3 = \frac{\pi}{4} \times \text{Diameter}^2, \text{ ft}^2 \times \text{Depth, ft}; \text{ the term } \frac{\pi}{4} \text{ is equal to 0.785} \]
- Frequently, the volume is gallons, rather than cubic feet:
  \[ V, \text{ gal} = V, \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 \]
- To calculate the detention time (t) of any chamber, tank, basin, or clarifier:
  \[ t, \text{ min.} = \frac{V, \text{ gal} \times \text{flow rate, gpd}}{\text{d}} \times (\text{h})(60 \text{ min}) \text{ or...} \]
  \[ t, \text{ h} = \frac{V, \text{ gal} \times \text{flow rate, gal/d}}{\text{d}} \times 24 \text{ h} \]

To determine the chemical feed rate or flow from a chemical feeder, the amount or volume fed during a known time period must be known. The flow from a chemical feeder can be calculated by knowing the volume pumped from a chemical storage tank and the time period.

- Flow, GPM = (Volume Pumped, gal)/(Pumping Time, min) or...
- Flow, GPD = (Volume Pumped, gal)/(24 hr/day)/(Pumping Time, hour)

Liquid polymer feed rates are often measured in pounds per day. To calculate this feed rate, the strength of the polymer
solution as a percent or as milligrams per liter, the specific gravity of the solution, the volume pumped, and the time period must be known.

- Polymer Feed, lb/day = (Polymer Concentration, mg/L)(Vol Pumped, mL)(60 min/hr)(24 hr/day)/(Time Pumped, min)(1,000 mL/L)(454 g/lb)

To determine the actual feed from a dry chemical feeder, the operator must know the pounds of chemical fed and the time period.

- Chemical Feed, lb/day = (Chemical Fed, lb)(60 min/hr)(24 hr/day)/(Time, min)

Detention times are calculated by dividing the volume in gallons by the flow in gallons per day. This produces the detention time in days. Multiply by 24 hours per day to obtain the detention time in hours. To convert the detention time from hours to minutes, multiply by 60 minutes per hour. To convert the detention time from hours to minutes, multiple by 60 minutes per hour and minutes to seconds multiple by 60 seconds per minute. Many operators prepare curves of flow versus detention time for the basins in their plants. These curves allow for easy selection of stirring times when performing jar tests.

Jar Testing

The purpose of jar testing is for operators to observe on a small scale how changes in chemicals, chemical doses, dosages, mixing times, and other parameters affect the plant’s performance. Jar testing consists of collecting a sample to be tested, adding the coagulant or other chemical with rapid mixing, followed by slow-mix flocculation, and then settling with the mixer turned off. After settling, a sample of the supernatant, the clear water on top, is taken to determine water quality parameters such as pH, turbidity, and alkalinity. Because the idea is to test variations, particularly, in chemicals or doses, multiple jars are usually run in parallel.

The goal is to simulate the full-scale plant; however, it is almost impossible to exactly duplicate in a laboratory experiment the flow-through conditions that are occurring in the treatment plant. Nevertheless, the goal is for the jar test results to accurately reflect how the plant will respond to the chemicals being tested. In the jar testing procedure, the mixing time should be the same as the hydraulic detention time in the plant’s flocculation basins. On the other hand, the settling time should not be the same as that in the plant because the particles are settling only a few inches in the jar and many feet in the plant. Choose a settling time in which the jar turbidity is approximately the same as the settling tank effluent. Similarly, the rotations per minute set on the laboratory mixer should not be the same as those settings in the plant. The intensity of the mixing should be the same in each case; however, mixing intensity depends on the amount of mixing power delivered to the water per unit volume. Different kinds of mixers have different relationships between the mixing speed and the power delivered to the water. The relationship for the jar test mixer is different from the plant mixer, so the mixing time will be different as well. Adjust the laboratory mixer speed until the jar test results approximate the plant performance. Finally, because temperature can affect floc formation, jar tests should be run at about the same temperature as the plant water temperature. If this process is inconvenient to do regularly, then try to do a one-time experiment in which the same jar tests are repeated at different temperatures to get an idea of how big an impact the temperature variable has on test results.
Checking the Plant Performance against Jar Tests

It is wise to check the effectiveness of process changes based on jar test results. A process protocol that allows an operator to check the effectiveness of jar testing results is carried out as follows:

1. When the coagulant feeders are working properly collect a sample of well-mixed water from the effluent of the flash-mix chamber to finely adjust process performance. Take the sample to the lab and perform another jar test. First, test the chemical dosage to determine whether the dosage is too high or too low.

2. Fill two jars with the flash-mixed sample. The second jar is a check on the first in case the sample is not representative. Because the chemicals have already been mixed in the sample water, floc will start to form. Be sure the sample stays mixed while pouring off the volumes into the six jars for jar testing.

3. Mix the samples at the speed and time used in the original test.

4. Stop the stirrers. Allow floc to settle for 30 minutes or the time used in the original test. When stirrers are stopped, immediately collect a sample from the flocculation basin effluent. Fill an experimental jar for comparison with other jars.

5. In all of the jars, observe how quickly the floc settles, floc appearance, and turbidity of settled water above the floc. They should be similar.

6. Evaluate the jar test results and make further process adjustments as appropriate.

Evaluation of Plant Performance

One of the best ways to evaluate the performance of the coagulation-flocculation process is to observe the process in the plant. During the walk through the treatment plant, the operator should take some clear plastic beakers. Obtain some water out of each stage of the treatment process. Hold the sample up to a light and look at the clarity of the water between the floc and study the shape and size of the floc. Study the development of the floc from one flocculation chamber to the next and into the sedimentation basin.

1. Observe the floc as it enters the flocculation basins. The floc should be small and well-dispersed throughout the flow. If not, the flash mixer may not be providing effective mixing, or the chemical dose or feed rate may be too low.

2. Tiny floc may be an indication that the chemical coagulant dose is too low. A popcorn flake is a desirable floc appearance. If the water has a milky appearance or a bluish tint, the dose is probably too high.

3. As it moves through the flocculation basins, the size of the floc should be increasing. If the floc size increases and then later starts to break up, the mixing intensity of the downstream flocculators may be too high. Try reducing the speed of the flocculators, or increasing the polymer dosage.

4. Look for the floc settling out in the sedimentation basin. If a lot of floc is observed flowing over the laundering weirs, the floc is too light to settle during the detention time produced by the flow rate. By increasing the chemical coagulant dose or adding a coagulant aid such as a polymer, a heavier, larger floc may be produced. The appearance of fine floc particles washing over the effluent weirs could be an indication of too much coagulant and the dose should be reduced. Regardless of the problem, make only one change at a time and evaluate the results.

5. Bring some beakers with samples from various locations back to the laboratory, let them sit for a while, and then observe the floc settling.

6. Evaluate the filter performance.
Calculating the Amount of Chemical Required

In calculating the amount of a chemical that should be added to the water for treatment, the operator must know the flow in gallons per day and millions of gallons per day. Then, using the dosage determined through jar testing, the pounds of chemical per day can be calculated.

- \( \text{Lbs per day, chemical} = \text{Flow Rate, MGD} \times \text{dosage, jar testing mg/L} \times 8.34 \text{ lbs/day} \)

Chemical Feeding

The chemical feed rate delivered by chemical feeders must be checked regularly. Jar tests will show the best dosages of chemicals in mg/L. To check on the feed rate delivered by a chemical feeder, measure the volume (in gallons for a liquid chemical feeder) or the weight (in pounds of a dry chemical feeder) delivered during a 24-hour period. The flow during this time period also needs to be known and is recorded in gallons per day or million gallons per day. In this calculation, the operator must know the flow rate in millions of gallons per day and the total amount of chemical feed in pounds.

- \( \text{Chemical used, lbs per day} = \text{Flow rate, MGD} \times \text{chemical dosage, mg/L} \times 8.34 \text{ lbs per gallon} \)
- \( \text{Chemical, lbs/day} = (\text{Flow rate, MGD})(\text{chemical dosage, mg/L})(8.34 \text{ lbs/gal}) \)
- \( \text{Chemical dosage, mg/L} = (\text{Chemical, lbs/day})/(\text{Flow rate, MGD})(8.34 \text{ lbs/gal}) \)

Preparation of Chemical Solutions

Polymers are frequently used as coagulant aids. Polymers are often supplied as dry chemicals, and operators usually need a specific solution concentration (mg/L or percent solution). The solution concentration depends on the type of polymer and the polymer's molecular weight of the polymer. The higher the molecular weight the polymer is the more difficult it is to mix the polymer with dilution water and to feed the resulting solution to the water being treated; in higher molecular weights, the problem is that the solution becomes very viscous. Therefore, anionic and nonionic dry polymers used as coagulant aids are prepared as very dilute solutions. Cationic polymers in the dry form can be prepared at higher solution concentrations because their molecular weights are small.

High molecular weight polymers are difficult to prepare. To be effective, polymer solutions must be the same throughout (homogeneous). They must be thin enough to be accurately measured and pumped to the flash-mix chamber.

When mixing a dry polymer with water, sift or spread the polymer evenly over the surface of the water in the mixing chamber. The polymer should be sucked evenly into the hole (vortex) of the stirred water. This process will ensure that each particle of polymer is set individually. This process will also ensure even dispersion and prevent the formation of large, sticky balls of polymer that have dry polymer in the middle.

Excessive mixing speeds, mixing time, and the buildup of heat can break down the polymer chain and reduce its effectiveness.

High concentrations of polymer result in very thick, sticky solutions. Prepare and use concentrations of polymers that can be metered and measured easily and pumped accurately to the flash mixer.
Adding dry polymer to water must be done in a closed system or under an efficient dust collector. Polymer powders on floors and walkways become extremely slippery when wet and are very difficult to remove. In the interest of safety, keep polymers off the floor. Use an inert, absorbent material, such as sand or earth, to clean up spills.

When mixing dry or liquid polymers, follow the directions of the polymer supplier. Polymer solutions are usually prepared in batches or as a batch mixture. Often they are stored after mixing in a day tank or an aging tank to allow time for all the powder to dissolve or the solution to become completely mixed.

To prepare a specific percent polymer solution, use this formula:

- Polymer, % = (Dry Polymer, lbs x 100%)/(Dry Polymer, lbs + Water, lbs)
- Dry Polymer, lbs = ((Water, lbs x 100%)/(Polymer, %)) - 1.0
- Water, lbs = ((Dry Polymer, lbs x 100%)/(Polymer, %)) - Dry Polymer, lbs
- Water, gal = Water, lbs x gal/8.34 lb

When working with liquid polymers, usually the supplier provides the percent polymer in the liquid polymer. The problem is to determine how much of the supplier’s polymer should be mixed with water to produce a tank or barrel of coagulant with a diluted or lower percent polymer.

- P_{polymer} \times V_{polymer} = P_{solution} \times V_{solution}

Where:

- P_{polymer} = Percent polymer provided by the supplier
- V_{polymer} = Volume of the polymer from the supplier
- P_{solution} = Percent polymer needed
- V_{solution} = Volume of the polymer after adding water to the solution from the supplier
- P_{solution} = (P_{polymer} \times V_{polymer})/V_{solution} or...
  - V_{solution} = (P_{polymer} \times V_{polymer})/P_{solution}

Review Questions

1. Calculate the applied feed dosage rate if 3 million gallons of water is treated with 100 pounds of chlorine gas.
2. What is the flow rate in gallons per minute if the total daily flow is 2.4 million gallons/day?
3. What is the applied dosage rate for a water treatment plant with a flow of 4.1 million gallons per day in pounds per day if the chlorine dosage is 3.8 mg/L?

Test Questions

1. Which of the following does not have an effect on the speed of flocculators in the coagulation/flocculation process?
   1. Volume of floc to be formed
   2. Visual observations of short-circuiting
3. Water temperature
4. Chlorine demand

2. The most important consideration in coagulation-flocculation process control is _________.
   1. Selection of the proper type and amount of coagulant chemicals
   2. The flow rate
   3. Water temperature
   4. Chlorine demand

3. The term ________ describes the effect produced when certain chemicals are added to raw water containing slowly settling or non-settleable particles.
   1. flocculation
   2. coagulation
   3. filtration
   4. disinfection

4. ________ is a physical and chemical reaction occurring between the alkalinity of the water and the chemical added to the water, which results in the formation of insoluble flocs.
   1. flocculation
   2. coagulation
   3. filtration
   4. disinfection

5. ________ is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles.
   1. flocculation
   2. coagulation
   3. filtration
   4. disinfection

6. Calculate the amount of a chemical in pounds per day that should be added to water for treatment, when the flow is 830,000 gallons per day and the dosage determined through jar testing is 11 mg/L of alum.