1.4: Coagulation and Flocculation

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- Coagulant types
- Coagulation chemistry
- Mixing systems for both coagulation and flocculation
- Flocculation process theory
- Pounds formula

One of the most important steps in the water treatment process is the removal of suspended solids. The two-part process in water treatment involves chemical deactivation and physical removal of pathogenic organisms. The physical removal of pathogens is accomplished in several steps. The first two steps include the processes of coagulation and flocculation. In this process, colloidal particles are destabilized to gather all the suspended material together. They can also be referred to as nonstable solids. This process increases particle sizes which assists in removal during the filter process. The larger floc particles will be removed during the sedimentation and filtration process. Coagulation occurs very quickly in the rapid mix or flash mix process. The flash mix process only lasts several seconds as the coagulant rapidly mixes and reacts with the raw untreated water. The floc will gain in size during the second step of flocculation. Filtration cannot occur without proper coagulation and flocculation.
Coagulant Types

In general, two types of coagulants are used during coagulation. A **primary coagulant** and a **coagulant aid** will be used during the rapid mix process. The colloidal surfaces are negative thus positively charged metal salts are used as primary coagulants. The coagulant dissolves in water and ionizes. To ionize is when a molecule loses or gains an electron to form an ion. The three most common coagulants used in water treatment are Aluminum Sulfate (Alum), Ferric Sulfate, and Ferric Chloride. The most commonly used primary coagulant in water treatment is Alum because of its wide availability and affordability.

Synthetic polymers are often used as a coagulant and filter aid but have also been used as a primary coagulant. Operators use different charged groups of polymers known as cationic (positive), anionic (negative), and nonionic (without ionizable groups). Coagulation aids assist in the building of settable floc.

Important things to consider when choosing a polymer:

- Overdosing a polymer can decrease the efficiency of the coagulation process and cause filter binding and increased headloss in filters.
- Not all supply water is created equal. Every single water source has a different chemistry and jar tests must be performed to see what polymer works best with the specific source water.
- There is no widespread standard for choosing a polymer. Different states have chemical approval standards that must be met.
- The addition of chlorine can affect polymer effectiveness.
- As with any chemical, there is a dosage limit.
**Chemistry**

Like many processes in water treatment, the theory of coagulation is very complex. As an operator, you should have a basic understanding of the chemistry involved in each process. The coagulant added to the water will react with the alkalinity in the water to form insoluble floc. Insoluble is something that will not dissolve. If the floc is not formed properly, then operators cannot effectively remove pathogens from the treated water. Alkalinity is not the same as pH. This gets very confusing as “alkaline water” has become a more widely popularized marketing term. Alkalinity is the water’s ability to neutralize an acid based on its makeup of carbonate, bicarbonate, or hydroxide. The measure of alkalinity is the amount of acid that would have to be added to water to lower the pH to 4.5 and there is where the confusion arises.

Coagulation is most effective in the pH range of 5-7 because of the waters ability to react with alkalinity. In this range, the water tends to buffer or stay in the same pH range and will allow the complete mixing of coagulant chemicals. If the raw water has a low pH, agents such as soda ash can be added to increase the pH.

Proper water quality tests must be performed by operators to promote the proper addition of coagulant chemicals. Underdosing coagulants will cause problems with floc formation while overdosing coagulants can cause clogging during the filter process. Clogged filters lead to head loss problems in the filters and increased filter washing.

**Mixing**

As noted earlier the coagulation process is completed within a matter of seconds. Mixing can be achieved by utilizing hydraulic mixers, mechanical mixing, diffusers, or pumped blenders. Hydraulic mixers use flow to achieve mixing. This kind of mixing requires enough flow to create a disturbance in the water to achieve proper mixing. Mechanical mixers require the greatest amount of energy because they require an electrical source to achieve mixing. Diffusers apply uniform flow during the coagulation process but may require many adjustments after flow changes. Finally, pumps can be used to push coagulant into water flow. Mixing can occur in a basin, channel, or pipeline.

**Flocculation**

*Flocculation* is the slow mixing process that causes smaller particles to merge into larger particles that settle more easily. The particles are then more easily removed in the sedimentation and filtration process. The process of flocculation is achieved by controlling the rate of impacts between particles as they gain size. Floc size can range between 0.1 mm-3 mm. The size of the floc produced depends on which type of treatment process is utilized at a specific plant. It is important that floc has good size but also density so the floc will not shear during the sedimentation and filtration process. This process is much longer than coagulation lasting roughly 15-45 minutes.
Shown Above: The flash mix portion is also known as coagulation. The chemicals are added together and the process occurs within seconds. After flash mix, the water heads to the flocculation basins to allow floc particles to gather in size.

Mechanical flocculators can be installed both horizontally and vertically. The horizontal type utilizes paddle-style mixers while the vertical style mixers can include paddle, turbine, and propeller style mixers. The shape and size of a flocculation basin is determined by the type of mixing used and the adjacent structures such as the sedimentation basins. Flocculation basins are usually split into 3 compartments. The speed of the mixing is decreased in each compartment to prevent the particles from breaking apart as they become larger. If the particles break apart during flocculation, the particles will place a heavier burden on the filters during the filtration process causing lower filter run times. This phenomenon will be discussed in further detail in Chapter 6.

**Monitoring and Process Control**

The coagulation and flocculation process requires a great amount of attention to detail along the way. An operator cannot just set a dose and “hope” everything works out. Water quality can change frequently and operators must ensure they are on top of changing conditions. One way an operator can achieve this is through jar testing. This is a laboratory procedure that finds the best coagulant dose based on water quality conditions.

Figure \(\PageIndex{3}\): Image of a jar test by Jigchen L. Norbu is licensed under [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/)

The efficiency of water treatment plants is determined by the combined effluent turbidity reading. Individual filter efficiency is also closely monitored. This will be discussed at length in the filtration chapter of the text, but it’s important to have a basic grasp of that concept at this point in the treatment process. Water treatment is a lengthy process. What’s occurring right now can have grave impacts down the line in the treatment process. Because of this consideration, jar testing and plant monitoring is all the more critical. Jar testing and laboratory grab sampling ensure the water which is theoretically being treated now, will be safe when entering the distribution system hours from now.
During abnormal conditions, it is important for operators to take notes and inform senior operators and/or a supervisor. Record keeping is important because operators can go back to notes used from previous experiences. For example, a large rain event has changed the influent turbidity entering the treatment plant. A similar event happened three years prior and the influent turbidity is very similar to the ones operators are seeing currently. Wouldn’t it be nice to have a record of what the operators did three years ago? Hopefully, the operations staff from three years ago noted changes in coagulant dose, mixing speeds, chlorine demand, and other significant plant changes.

Enhanced Coagulation

The **enhanced coagulation** process is used to remove natural organic matter by adjusting the pH and coagulant dose to remove the greatest amount of suspended matter during the treatment process. The addition of acid is used to achieve the proper pH unlike sweep treatment were the operator overdoses the coagulant to achieve the correct pH range. Enhanced coagulation occurs at a lower pH, and accordingly will see improvements in treatment such as:

- Humic and fulvic molecules separate better with lower pH. Humic and fulvic acids are organic acids commonly found in raw water sources
- Less coagulant is required for treatment
- Flocculation improves at a lower pH
- Sulfuric Acid addition before coagulant is added preconditions organic matter

The Pounds Formula (Chemical Dosage Problems)

One of the most important calculations an operator will use is the “Pounds Formula.” The pounds formula can be used to solve water math problems including milligrams per liter to pounds per day, feed rate, chlorine dosage, percent strength, and dilution calculations. The formula for the pounds calculations is:

\[
\text{Feed Rate (lbs/day)} = \text{dosage (parts per million)} \times \text{Flow Rate (million gallons per day)} \times 8.34 \text{ lbs/gal}
\]

Below is the pounds formula expressed in a mechanical wheel. The mechanical wheel can be used to solve a chemical dosage problem by plugging in the given information and then multiplying or dividing as indicated to determine the solution. For example, a treatment plant will produce 2 MG a day. The chlorine dose is 3.0 mg/L. How many pounds of chlorine will the operator use?
Feed Rate = 3.0 \times 2 \times 8.34 \\
Feed Rate = 50 \text{ lbs/day}

It is important to note that when using the pounds formula, the water production is always expressed in MGD. For example, a problem may ask what the chlorine production is for a water treatment plant that produces 1,000,000 gallons a day. This is the easiest expression because $1,000,000 \div 1,000,000 = 1$.

EX: A water treatment operator must super chlorinate a 650,000-gallon tank at 50 ppm. How much chlorine must the operator add?

\[ 50 \times 0.65 \times 8.34 = 271 \text{ pounds} \]

* You must divide 650,000 by one million to get .65 to solve the equation. Round to the nearest tenth or hundredth place to get the most accurate answer. Remember you must show all work during exams to get credit but the format is still multiple choice so be careful when rounding.

**Practice Pounds Formula Problems**

Example \( \PageIndex{1} \)\)

The dry alum dosage rate is 15 mg/L. The daily flow rate of a treatment plant is 5 MG. How many pounds of dry alum per day is required?

**Solution**

\[ \text{Feed Rate} = 15 \text{ mg/L} \times 5 \text{ MGD} \times 8.34 \text{ lbs/gal} \]

Feed Rate = 625.5 lbs/Day

* This sample problem is pretty simple. Plug the numbers into the equation and multiply to get your answer.
Example \(\PageIndex{2}\))

A treatment plant uses 300 lbs of alum a day. The plant output is 2,500,000 gallons a day. What is the dose?

**Solution**

Step 1: \(2,500,000 ÷ 1,000,000 = 2.5\) MGD

Dose = \(300\) lbs/day/(2.5 \(\times\) 8.34)

Dose = 250/20.85

Dose = 12 mg/L

Example \(\PageIndex{3}\))

How many pounds of 65% available chlorine must an operator add to a treatment plant with a dose of 3.0 mg/L and a plant output of 5 MGD?

**Solution**

* Start the equation as you normally would. Since you are adding a solution of chlorine that is not 100 percent an extra step is needed to solve the problem. Remember, if the chlorine solution is not 100 percent available chlorine you are going to need more to dose properly!

Feed Rate = 3.0 \(\times\) 5 \(\times\) 8.34 = 125 lbs/day

Next, you will need to make an adjustment based on chlorine strength.

\((0.65)(x\ lbs/day) = 125\ lbs/day\)

\(x = 125.65\)

\(x = 192\ lbs/Day\)

Note: If the number is smaller than the original number, you multiplied instead of dividing. You will always need more chemical if it’s not 100% strength.

Example \(\PageIndex{4}\))

A water tank that is 30 ft high and 100 f in diameter must be dosed at 50 ppm for disinfection. How many pounds of 65% calcium hypochlorite must be added to dose the tank?

**Solution**

\[0.785 \times 100\text{ft} \times 100\text{ft} \times 30\text{ft} \times 7.48\ \text{Gal/ft}^3 = 1,761,540\ \text{gallons}\]

\[1,761,540\ \text{gallons}/1,000,000 = 1.76\text{MGD}\]
Feed Rate = 50 × 1.76 × 8.34 = 733.92 pounds/day

(.65)(x) = 734

x = 734/.65

x = 1129 lbs

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**Chapter Review**

1. The optimal coagulant dose is determined by a ___________.
   1. Chlorine test
   2. Flocculation test
   3. Jar test
   4. Coagulation test

2. The most common primary coagulant is ___________.
   1. Alum
   2. Cationic polymer
   3. Fluoride
   4. Anionic polymer

3. Bacteria and viruses belong to a particle size known as ___________.
   1. Suspended
   2. Dissolved
   3. Strained
   4. Colloidal

4. The purpose of coagulation is to ___________.
   1. Increase filter run times
   2. Increase sludge
   3. Increase particle size
   4. Destabilize colloidal particles

5. The purpose of flocculation is to ___________.
   1. Destabilize colloidal particles
   2. Increase particle size
   3. Decrease sludge
   4. Decrease filter run times

6. Primary coagulant aids used in the treatment process are ___________.
   1. Poly-aluminum chloride
   2. Aluminum sulfate
   3. Ferric chloride
4. All of the above

7. Flocculation is used to enhance ___________.
   1. Number of particle collisions to increase floc
   2. Charge neutralization
   3. Dispersion of chemicals in water
   4. Settling speed of floc

8. If there is a problem with floc formation, what would you consider changing?
   1. Adjust coagulant dose
   2. Stay the course
   3. Adjust mixing intensity
   4. Both 1 and 3

9. Which step in the treatment process is the shortest?
   1. Filtration
   2. Sedimentation
   3. Flocculation
   4. Coagulation

10. To lower the pH for enhanced coagulation the operator will add ___________.
    1. Chlorine
    2. Sulfuric acid
    3. Lime
    4. Caustic soda

11. The flocculation process lasts how long?
    1. Seconds
    2. 5-10 minutes
    3. 15-45 minutes
    4. Over an hour

12. The function of a flocculation basin is to ___________.
    1. Settle colloidal particles
    2. Destabilize colloidal particles
    3. Mix chemicals
    4. Allow suspended particles to grow

13. A treatment plant has a maximum output of 30 MGD and doses ferric chloride at 75 mg/L. How many pounds of Ferric Chloride does the plant use in a day?
    1. 18,765
    2. 17,765
    3. 19,765
    4. 16,765

14. A treatment plant uses 750 pounds of alum a day as it treats 15 MGD. What was the dose rate?
1. 4 mg/L
2. 5 mg/L
3. 6 mg/L
4. 7 mg/L

15. A treatment plant operates at 1,500 gallons a minute and uses 500 pounds of alum a day. What is the alum dose?
   1. 18 mg/L
   2. 28 mg/L
   3. 8 mg/L
   4. 38 mg/L