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# Fundamentals of Coagulation and Flocculation

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# Fundamentals of Coagulation and Flocculation

## Educational Objectives

Upon completion of this Contact Hour, the operator should understand what a colloidal particle (turbidity) is and the processes to remove them using the coagulation and flocculation process. The operator should also understand coagulants, coagulant aids and jar testing.

### I. Abstract

This Contact Hour defines colloidal particles and the processes of coagulation and flocculation, as related to removing turbidity from drinking water. Included are the characteristics of coagulants and the basics of flocculation. Jar testing, used to select coagulants and optimize the coagulation/flocculation process, is also addressed.

### II. Keywords and Definitions

Take a glance through this list and be sure to read carefully any terms or abbreviations with which you are not familiar.

**Colloidal Particles:** Turbidity; very small solids; finely divided particles of matter, which range in size from 1 – 500 nanometers (nm) or millimicrons (mm), dispersed within a continuous medium in a manner that prevents them from being filtered easily or settled rapidly and shelters bacteria from disinfection.

**Turbidity:** Muddiness or cloudiness created by stirring up sediment or having foreign particles suspended; turbidity is composed of very small solids (colloidal particles) with a diameter less than 0.5 microns.

**Coagulation:** The change from a liquid to a thickened, curd-like, insoluble state by some kind of chemical reaction.

**Flocculation:** The process by which small particles of fine soils and sediments aggregate into larger lumps; during flocculation, the water is slowly agitated to allow the colloidal particles to bump into each other and agglomerate into larger and heavier flocs.

**Coagulant:** Chemicals (coagulants) are added to the water to allow colloidal particles to agglomerate or come together to

form floc; some coagulants also form gelatinous masses that sweep the flock from the water by sedimentation.

**Coagulant aid:** A substance or process that assists or causes a liquid to thicken or coagulate.

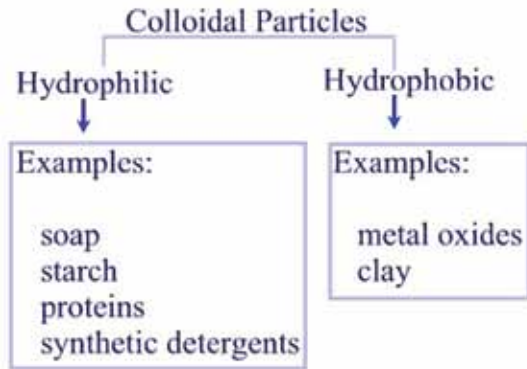
**Jar Test:** Performing procedures in small containers; the best coagulant, coagulant aid, chemical dosage, mixing speed, and flocculation time can be evaluated through a laboratory jar test; in a jar test, a paddle stirrer is used to blend and slowly agitate multiple samples.

### III. Introduction

Turbidity (colloidal particles) originates from clay, microscopic organisms, municipal wastes, color compounds, and organic matter. A colloidal particle ranges in size from 1 – 500 nanometers (nm) or millimicrons (mm). Their presence in drinking water makes it appear cloudy (turbid) and shelters bacteria from disinfection. Their small size results in an extremely slow settling time and causes them to pass through a typical filter. For example, a colloidal particle with a 1 nm diameter has a settling velocity of 3 meters per million years. Because of the health and aesthetic issues they must be removed. Most surface water that is used for drinking in the United States is treated with the process of coagulation/flocculation to remove colloidal particles (turbidity). The maximum average amount of turbidity allowable in drinking water is 0.5 NTU, although infrequent spikes up to 5 are allowable.

There are two types of colloidal particles: hydrophilic and hydrophobic. Hydrophilic particles are stable (do not readily agglomerate to form larger particles that could settle more quickly) because they have an affinity for water. Examples include soap, starch, proteins, and synthetic detergents. Hydrophobic particles do not have an affinity for water and are stable because of their electrical charge. Particles with a positive charge are usually metal oxides, and particles with

a negative charge are usually clay. The majority of colloidal particles are hydrophobic.



Colloidal particles are removed from drinking water by coagulation/flocculation. Chemicals (coagulants) are added to the water to allow the colloidal particles to agglomerate or come together to form floc. Some coagulants also form gelatinous masses that sweep the floc from the water by sedimentation. Different chemicals or coagulants may be added depending on the characteristics of the colloidal particles to be removed.

#### IV. Destabilization

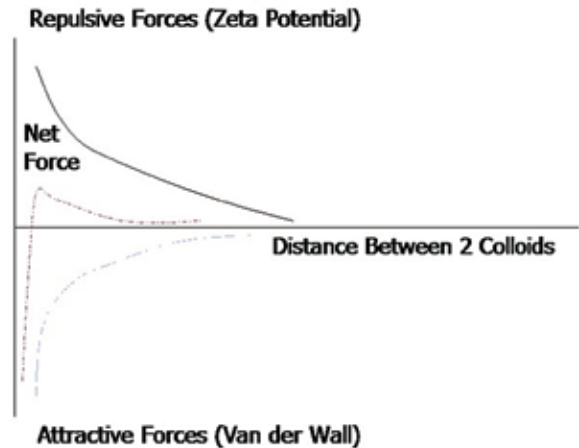
Hydrophobic colloidal particles remain suspended in solution because they repel each other due to the like charges they have adsorbed from solution and that remain on their surfaces. The magnitude of the particles repulsive forces is called the zeta potential. Destabilization occurs with the addition of chemicals that reduce the repulsive forces between the particles or lower the zeta potential. Destabilization takes advantage of the natural attraction between any two masses known as Van der Waals force. In a colloidal suspension, the force of the zeta potential is greater than the Van der Waals force. Thus, the particles repel each other and do not agglomerate into larger particles that can settle out of solution.

There are several mechanisms that allow the coagulant to destabilize colloids. In one, the coagulant increases the ionic strength of the water and compresses the thickness of the charged layer around each colloidal particle through repulsion. This allows the Van der Waals forces to draw the particles together to form floc. Some coagulants directly neutralize the surface charge of the colloidal particles allowing the Van der Waals forces to predominate and pull the particles together. In another mechanism, the coagulant removes the colloidal particles by sweeping or bridging them into a precipitate mass.

The figure below illustrates this concept. The Zeta Potential causes the colloidal solids to stay apart because like charges repel. Van der Waals forces cause colloidal solids to attract. The net force line in the graph shows the combination of the two forces and indicates once the particles get close together and overcome the sharp peak of repulsive forces, they will attract. A coagulant will neutralize the charges (Zeta

Potential) lowering that peak allowing the solids to attract to each other at further distances apart. See below.

#### Forces Associated with Colloidal Solids



#### V. Coagulants and Coagulant Aids

Coagulants are divalent or trivalent cations (they have a +2 or +3 charge, respectively) or polymers. The most common trivalent cations are usually aluminum and iron salts. The most common trivalent coagulants include aluminum sulfate or alum,  $Al_2(SO_4)_3$ , and ferrous sulfate,  $FeSO_4$ . Lime,  $Ca(OH)_2$ , is the most common divalent coagulant. Polymers can also be used as coagulants, but because of their expense, are more commonly used as coagulant aids. They result in larger flocs that are tougher, or less likely to disintegrate.

These coagulants and an aid can be used singly or in combination to treat water. Sometimes additional turbidity (clay) is also added to allow for more rapid floc formation. To select the proper coagulant and dose, the literature is first consulted. Many sources contain tables that match the coagulant with the physical and chemical characteristics of the water including pH, alkalinity, organic content, and original turbidity. Vendors also maintain a data base of the appropriate applications of coagulants. However, the selection and dose must be optimized through jar testing. This process is discussed in greater detail later in this class.

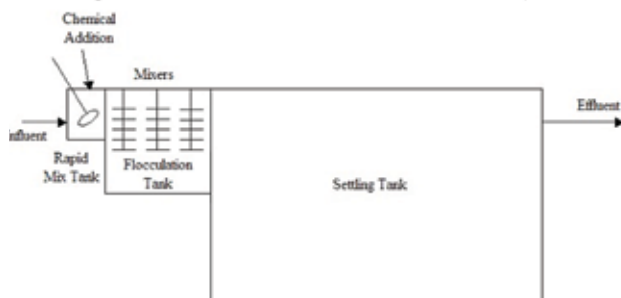
The most common problems associated with coagulation are weak flocs that do not stay together long enough to settle completely or flocs that settle poorly. Coagulant aids may be added to reduce or eliminate these problems. Depending on the specific characteristics of the water, it is not necessary to always use an aid. The addition of a coagulant aid may also reduce the amount of coagulant that is required. Coagulant aids may be nonionic or anionic polymers, sodium aluminate, activated silica, clay, acids, or alkalis.

#### VI. Coagulation/Flocculation System

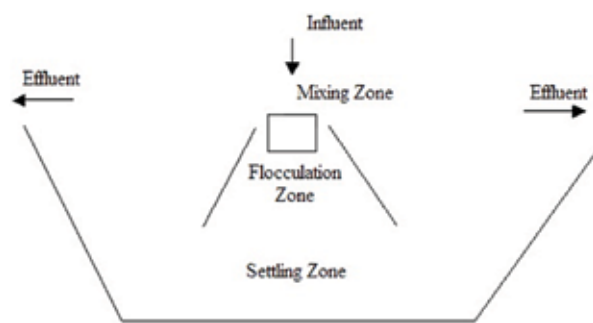
To achieve coagulation/flocculation, 3 basins are used. The first is rapid mixing, used to mix the coagulant with the water. Next, the colloidal solids are allowed to floc together to form

heavier, larger solids. These solids are settled out in a basin. Alternatively, all three steps can be achieved in one unit, a flocculating clarifier. The schematics below show a 3-tank system a flocculating clarifier. Each is described in more detail in the following sections.

### Coagulation/Flocculation, Three Tank System



### Flocculating-Clarifier

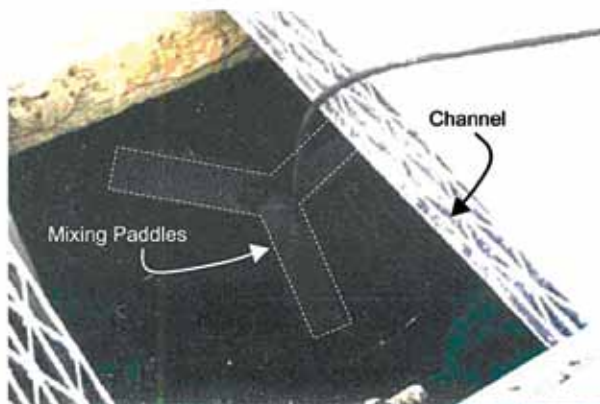


The design of each unit is based on the required detention time, mixing, and typical dimensional relationships as determined by standard values based on research and experience and jar testing, to be further discussed in a sequential section.

### VII. Rapid Mixing

Rapid mixing is used to contact the coagulant with the water to be treated, typically using mechanical mixing or, less often, a hydraulic jump. Complete blending should occur in 10 – 30 seconds. In general, a square tank is best. Below is a picture of a mechanical fast mixing tank. Note the flat bladed impellor inside the tank.

#### Rapid Mixing Tank



### VIII. Sedimentation

Once flocculation is complete, the water flows into a sedimentation basin to permit the floc to settle out. The solids are wasted through the bottom and the water flows out of the basin via weirs. See the 360Water Primary Treatment Class, in the Wastewater Fundamentals.

#### Sedimentation Basin



### IX. Flocculator-Clarifiers

The discussion thus far described the three units needed for coagulation/flocculation. It uses a system of three independent tanks. An alternative is a flocculator-clarifier (shown below), which is also known as a solids contact unit or an up-flow tank. Mixing, flocculation, and sedimentation all occur in one tank. These units require less space than separate tanks but offer less operating flexibility.

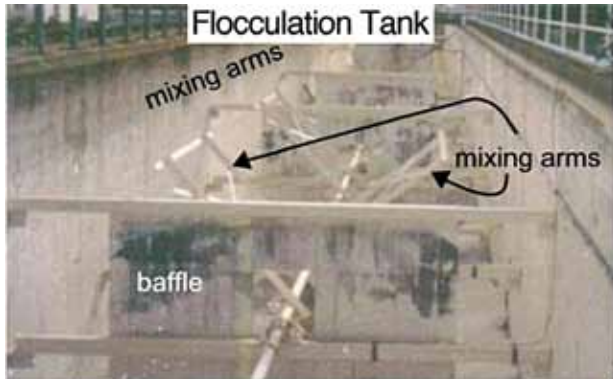
#### Flocculator-Clarifiers



### X. Flocculation

Once the coagulant and any desired coagulation aids have been blended using rapid mixing, flocculation begins. During flocculation, the water is slowly agitated to allow the colloidal particles to bump into each other and agglomerate into larger and heavier flocs. Mixing can be achieved with paddle flocculators, flat blade turbines, and vertical turbine mixers. Based on experience, it has been determined that the optimal flocculation system should consist of a minimum of three tanks, in series, or three sections within one tank. In either

case, there should be progressively slower mixing throughout the tank or tanks. The water should travel at a velocity of 0.5 - 1.5 feet /minute and at least 30 minutes should be allowed for flocculation. The picture below shows a flocculation tank with paddle mixing arms.

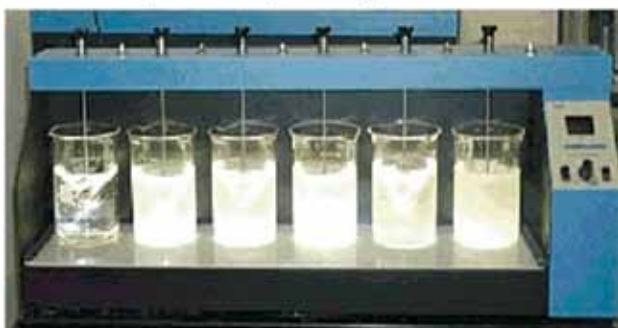


## XI. Jar Testing

The U.S. EPA has recently developed a protocol for enhanced coagulation/flocculation that calls for jar testing to optimize the coagulation/flocculation process. This is designed to maximize pathogen removal by maximizing turbidity removal. As a result, the aesthetic quality is also improved. The best coagulant, coagulant aid, chemical dosage, mixing speed, and flocculation time can be evaluated through a laboratory jar test. In a jar test, a paddle stirrer is used to blend and slowly agitate multiple samples. Rapid mixing occurs at a speed of 60 – 80 rpm for 1 minute and slow agitation occurs at a speed of 30 rpm for approximately 15 minutes. Part of the purpose of jar testing, however, is to optimize these values. The two pictures below show a jar test undergoing rapid mixing and flocculation, respectively. The mixer is then turned off and the floc is allowed to settle.

The picture below shows a close up of the results of three jar test samples after sedimentation. There is a clear difference in the quality of the samples.

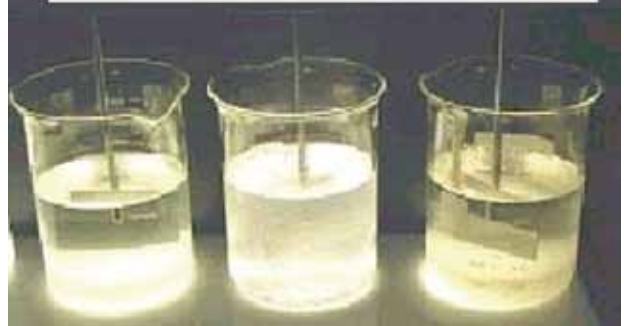
**Rapid Mixing During a Jar Test**



**Flocculation During a Jar Test**



**Jar Testing at the Completion of Sedimentation**



## XII. Optimized Colloidal Removal

The removal of colloidal solids from potable water is critical for two reasons. Some colloidal solids are pathogens, including protozoa such as cryptosporidium. Larger microorganisms are difficult to disinfect. Further, colloidal solids also can shelter attached pathogens making disinfection difficult. If very clear water is not produced, there is a probability that pathogens are present. Colloidal solids may also be organic materials that can be precursors for the formation of disinfections byproducts that can be carcinogens. Disinfection byproducts are synthesized when chlorine is added. They are regulated down to very low levels. Minimizing the organic materials minimizes the production of these dangerous by-products.

Because of the importance of both issues discussed above, the U.S. Environmental Protection Agency passed the Enhanced Coagulation/Flocculation Guidelines. This guideline emphasis is on the importance of conducting jar testing to optimize the removal of colloidal solids. Further, filtration polishes the water after coagulation/flocculation to ensure that flocs and larger non-flocculating solids are removed.

## XIII. Summary

This Contact Hour defined colloidal particles and the processes of coagulation and flocculation, as related to removing turbidity from drinking water. Included were the characteristics of coagulants and the basics of flocculation. Jar testing, used to select coagulants and optimize the coagulation/flocculation process, was also addressed.

## Online Completion

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## Questions

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| <p>1. Which of the following statements describe a colloidal particle? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Occasionally positively charged</li><li>B. Passes through a filter</li><li>C. Settles readily</li><li>D. Always hydrophobic</li></ul> <p>2. What is destabilization? Choose the best response.</p> <ul style="list-style-type: none"><li>A. The process of overcoming the zeta potential</li><li>B. The process of overcoming the Van der Waals forces</li><li>C. The process of determining the optimal coagulant, coagulant aid and settling time</li><li>D. The process of adding alkalinity for optimal coagulation</li></ul> <p>3. Which of the following may be used as a coagulant for drinking water treatment? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Trivalent Cation</li><li>B. Polymers</li><li>C. Lime</li><li>D. Divalent Anions</li></ul> <p>4. How is a coagulant selected? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Literature Review</li><li>B. Vendor Data</li><li>C. Jar Testing</li><li>D. Flocculator/Clarifier</li></ul> <p>5. Which of the following could be a benefit of using a coagulant aid? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Produce a stronger floc.</li><li>B. Produce a floc that settles more rapidly.</li><li>C. Use less coagulant.</li><li>D. Reduce the time required for rapid mixing.</li></ul> <p>6. Which of the following are used as coagulant aids for drinking water treatment? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Polymers</li><li>B. Clay</li><li>C. Divalent Cations</li><li>D. Gravel</li></ul> | <p>7. How are a coagulant and coagulant aid introduced to the water being treated? Choose the best response.</p> <ul style="list-style-type: none"><li>A. Rapid Mixing</li><li>B. Flocculation</li><li>C. Centrifuge</li><li>D. Clarifier</li></ul> <p>8. How should the water be mixed during flocculation? Choose the best response.</p> <ul style="list-style-type: none"><li>A. Slowly</li><li>B. Rapidly</li><li>C. No mixing should occur</li><li>D. Intermittently</li></ul> <p>9. What is the minimal time recommended for flocculation? Choose the best response.</p> <ul style="list-style-type: none"><li>A. 30 minutes</li><li>B. 30 seconds</li><li>C. 1 hour</li><li>D. 3 hours</li></ul> <p>10. What is being optimized in a jar test? Choose all that apply.</p> <ul style="list-style-type: none"><li>A. Mixing Speed</li><li>B. Dose of Coagulant</li><li>C. Mixing Time</li><li>D. Van der Waals Forces</li></ul> |
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# Fundamentals of Coagulation and Flocculation

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