Flocculation and Sedimentation

Station 1

Your assignment is to clean a sample of water so it meets the state requirements for drinking water. The challenge is to choose methods that are "green". What does it mean to be a **green engineer**? To work like a green engineer, you must consider the environmental impacts of your actions as well as the societal and economical impacts.

One important consideration for green engineers is the environment. They consider how their project adds to the amount of air pollution, water contamination, and waste production. In any project, the costs and benefits are an important economic consideration. These include the construction and operation of the project. Green engineers work hard to ensure the benefits of the project offset the costs. Green engineers also consider societal impacts of the project. Important societal considerations include determining the project impact on the human population. Green engineers may ask themselves, How will this project affect the poor in this community? Will the project change the standard of living for people of the area? How will be project influence the education of the citizens of this community?

For cleaning water, one thing to consider is the type and amount of chemicals you use in the water treatment process. You will have an opportunity to make "green" decisions as you design your water treatment system, but first you need to know some things about your water sample.

Look closely at the water sample at this station. Hold it up to the light. The cloudiness indicates it is not pure water. How can you remove unwanted substances from your sample? At this station, you will learn about one stage of water treatment designed to remove very small particles suspended in water. Work through each step with your team to learn more.

Step 1:

A. Examine the two test tubes of colored water. Use a hand lens to examine both tubes. In your journal draw labeled sketches and record your observations for each test tube.
B. Hold the laser pointer on the side of each tube and shine the light through the colored water. Again, draw labeled sketches and record your observations in your journal.

Think about this:

1. *What might cause the difference in what you saw in the two tubes?*

Step 2:

A **colloid** is a mixture made of insoluble microscopic particles dispersed within a medium. The particles are small and stable, and they do not settle. However, they are not dissolved in the medium. As a result, a colloid is not a solution. Colloids represent an intermediate state between a solution and a suspension. Like colloids, suspensions also have particles that are not dissolved. However, particles in a suspension are larger and will settle to the bottom of the container.

In the previous step, you saw evidence of a colloid and evidence of a solution. In one test tube, you were able to see a beam of light through the red liquid and in the other, you could not see the beam. Colloid particles are large enough to reflect light. As a result the light does not pass through the tube, but it reflects back to your eyes. Which tube contained a colloid?

Many common substances are colloids. The medium (the dispersing agent) can be gas, liquid, or solid, and the particles can be gas, liquid or solid (Figure 1).

Example	Particle	…in a…	Medium
gelatin	solid		liquid
shaving cream	gas		liquid
fog	liquid		gas
clouds	liquid		gas
milk	liquid		liquid
Styrofoam	gas		solid
mayonnaise	liquid		liquid

Figure1:Colloid examples
This is a partial list of some common colloids. Notice that the medium and the particle suspended in the medium can be a solid, liquid, or a gas.

Colloid particles range in size from 1 to 1000nm. They are often held in suspension by charge. The charged particles carry like charges and repel, preventing them from combining into larger particles to settle. For charged particles, gravity does not pull the particles out of suspension because the charge that holds them in place is greater than the pull of gravity. Chemists apply chemical and physical techniques to remove the charge so the small particles can combine into larger particles (**flocculate**). The resulting larger particles (sometimes feathery in appearance) are called **floc**. These larger particles settle to the bottom of the container in a process called **sedimentation**. See figure (2).

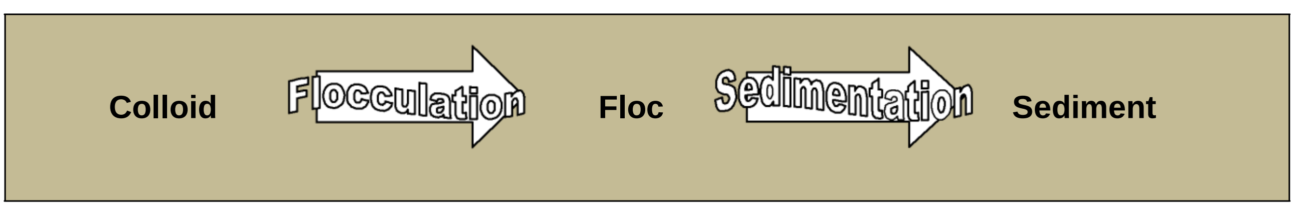

Figure 2: Process for removing colloids. Colloids are removed from a mixture through flocculation that builds larger floc particles that eventually settle as sediment.

Other factors can influence flocculation including changes in pH, temperature, and the chemical medium. Figure 3 shows how floc appears when the pH of a colloid is adjusted from 6 to 8.

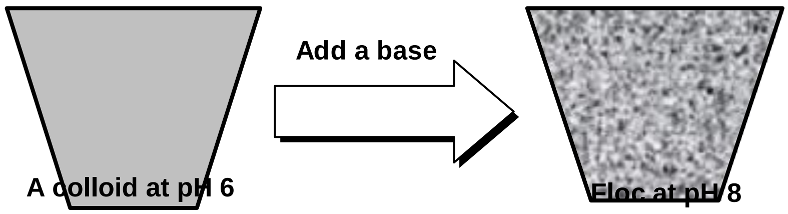

Figure 3: Adjusting the pH leads to flocculation.

Water treatment plants use various ways to flocculate the particles in water. These include changing the pH and using chemical flocculants. These methods remove the charge from the suspended particles allowing them to stick together.

Need to Know

In industry, you will hear the term coagulation and flocculation used for the process where smaller particles come together to form larger particles. **Flocculation** is similar to coagulation in that both refer to smaller particles clumping together to form larger particles. However, in flocculation the clumping stops before it becomes a continuous mass, a product observed in coagulation. The particles that form (**floc**) are often feathery in appearance.

Examine a typical water treatment plant to learn more about these processes.

http://water.ci.lubbock.tx.us/vids/waterTreatmentVid.aspx

Think About This:

2. *Look back to your answer to the "Think About This" question at the end of Step 1. Make revisions to your answer based on what you have learned. Make your revisions in a different colored pen or pencil.*

Step 3:

a. The glass at this step contains milk diluted with water. How can you confirm that this is a colloid? Try your idea. (For your investigation you may have to add a small amount of milk to a glass of water to better observe the results.)
b. You learned about flocculation in the previous step. Using what you learned, think of a way to alter the milk so the protein particles in the milk stick together.

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c. Design an investigation to test your hypothesis.
d. Get your teacher's approval and carry out your experiment.
e. Record your results in your journal.

Think About This:

3. *If you poured fresh milk through a filter, could you remove the protein? Why?*

4. *Would a filter remove the coagulated material? Why wouldn't this be a good idea?*

5. *Think of another way to remove the coagulated material. Think about the processes you viewed on the computer from Step 2. Record your ideas in your journal.*

6. *Ground water picks up clay particles as it travels through rivers and streams. The clay forms a colloid in the water. How could you remove the clay from the groundwater?*

Step 4:

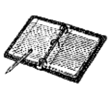
You learned about flocculation and sedimentation that remove small particles suspended in water. Does the dose of the flocculant matter? As a **green engineer**, you want to use the least amount of chemicals possible in your water treatment system. If you use too little flocculant, you will not remove enough of the particles. Excessive amounts of chemical are costly, but more importantly would add unwanted chemicals to the environment. Remember, as a **green engineer** you want to use the *least* amount of chemicals to accomplish your task.

Finding the proper dose of flocculant for your water sample is an important green engineering decision. In this step, you will collect data of your own and use class data to make this decision. The process you will use in this step (called the jar test) is one that engineers use to determine the proper amount for flocculation. You will measure the turbidity of the sample to determine how well you have removed the colloid particles. The particles in the water add to the **turbidity**, a measure of the “cloudiness” of your sample.

Complete the following steps with your team.

A. Design a procedure to determine the proper flocculant dose. Consider the following in your design:

   1. Use the Flocculation and Sedimentation Protocol in your design.
   2. You should have at least 4 different samples that can range in dose from 0 mL to 5 mL of alum solution.
   3. You will need two additional measurements: turbidity and pH before and after the process. A protocol for these measurements is also available.
   4. Flocculation is effective under a narrow pH range and you may have to adjust the pH for best results.
   5. The alum used in this protocol may change the pH to an unacceptable value, so you will need to measure pH.
   6. You will need a table to organize your data.



B. Get your teacher’s approval, and conduct your tests.

You will need the following materials:
3 L contaminated water, alum stock solution from your teacher, 1 L distilled water, graduated cylinder (1 L or 500 mL), .5 mL pipettes, graph paper (on line), pH meter, jar stirrer or stirring plate, spectrophotometer, cuvettes, Kimwipes, protocol, notebook.

C. Record your dose amounts and results on the class data sheet.

Once the whole class has results from this station, complete D - E using the whole-class data.

D. Graph your results as turbidity versus concentration of alum solution. See Appendix A for calculations.

E. Write a caption for your graph that explains the data and what dose you will choose for your water cleaning system. Explain why you will choose this dose.

> ***Hint:*** *A caption tells the story of your graph. The caption should be clear and concise. Include what you see in your data and what it means so that a reader can understand the results of your investigation. Also, explain what dose you will choose and why.*

Step 5:

As part of your water treatment system, you may choose to use the process of flocculation and sedimentation to remove the colloidal particles in the water. The amount of chemical you use is an important consideration for a **green engineer**.

Review the documents for the Research phase of the FRAME engineering design model. Now that you have completed this portion of the research phase, it is time to consider all of the possibilities that you have for this portion of your water treatment system.

Concentrate now on the flocculation and sedimentation part of your water treatment system as you complete "***Think About This***."

Think About This:

Begin to form your ideas for your design by identifying and describing possible solutions for this phase of water treatment. Follow 7-10 to help you with your plan. You may want to arrange 7-9 in a table format. Label this portion of your table, Flocculation and Sedimentation.

7. *Identify all possible ideas you have for using or not using this process in your water treatment system.*
8. *Make a list of everything you should consider for each possibility (materials, time, etc). Add details to your list (for example, list all the materials you will need).*
9. *Identify methods you will use to determine if each idea works.*
10. *Identify what you should consider when choosing the best solution.*

Teacher Pages

Background

The purpose of flocculation is to remove colloid particles in water. Colloids contain small suspended particles, and some have charges. Examples of charged particles are clay and bacteria, both of which have a negative surface charge. Due to the charge, the particles repel one another. As a result, the particles stay separate and suspended in the water, making them hard to remove. This repulsive force is stronger than gravity and thus the particles do not settle.

If the surface charge is removed or neutralized, colloid particles clump together and settle from solution. To destroy the negative surface charge, a positively charged chemical, called a coagulant or flocculant, is added to the water. In industry, the term coagulant and flocculant are used interchangeably. The best coagulants are trivalent cations (positively charged ions), such as the aluminum ion in aluminum sulfate ($Al_2(SO_4)_3$,).

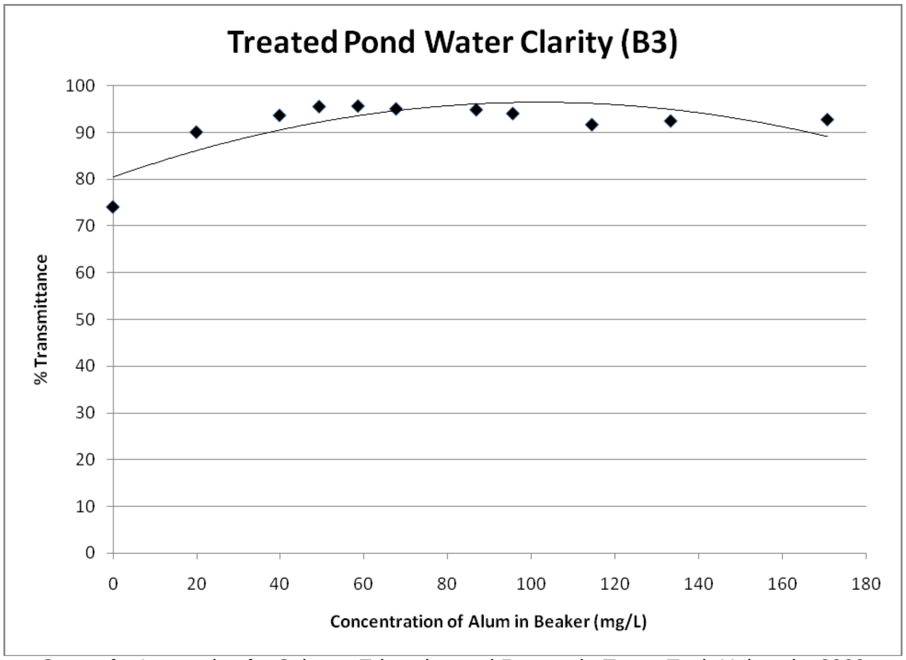
The water treatment industry often uses alum as the coagulant. However, there are many types of alum and the type may vary from one treatment plant to another. The most common alum is potassium aluminum sulfate ($KAl(SO_4)_2 \cdot 12H_2O$). This type of alum is commonly found in the grocery store labeled simply, alum. Other types of alum include ammonium alum ($NH_4Al(SO_4)_2 \cdot 12H_2O$), sodium alum ($Na_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$), chrome alum (potassium chromium sulfate ($CrK(SO_4)_2 \cdot 12H_2O$) and ferric ammonium alum ($FeNH_4(SO_4)_2 \cdot 12H_2O$).

The chemical reaction for aluminum sulfate is presented below.

$$Al_2(SO_4)_3 \cdot 18H_2O + 6H_2O \rightarrow 2Al(OH)_{3(s)} + 6H^+ + 3SO_4^{-2} + 18H_2O$$

To protect public safety, the coagulants need to be nontoxic since these will be added to water. Also, coagulants should be insoluble at water pH values between 6 and 8. If the coagulants dissolved in water, they would be unable to stabilize the colloid’s surface charge.

One important aspect of this process is that more coagulant is not better. An optimum dose of coagulant can be determined using the jar test. The optimal coagulant dose is the minimum dose generating the lowest turbidity value. The figure below shows alum dose vs. final turbidity measured as percent transmittance. At approximately 60 mg/L additional alum is no longer effective at decreasing turbidity.



Center for Integration for Science Education and Research, Texas Tech University 2009

At a water treatment plant, colloids are removed through a flocculation process. In your procedure, coagulation corresponds to protocol Step 3.

After rapidly mixing the coagulant and water to ensure the coagulant is evenly dispersed in the water solution, the mixing rate is decreased to allow the colloids to come into contact with each other and grow in size. These larger and now visible particles are called floc. The process of flocculation occurs during protocol Step 4.

After flocculation, water at the water treatment plant enters a very large tank. The velocity of the water is reduced and there is no turbulence at all. This process allows the floc in the water to settle out of solution. The processes at which suspended solids and floc settle from solution is called sedimentation. This step is done prior to filtration because the colloid particles will pass through a filter. Sedimentation is an important step since passing the floc through the filters would clog and damage the filter media.

Outcomes and Indicators of Success

By the end of this station, students should be able to

1. distinguish between colloids and solutions.
    a. they will demonstrate their ability by
    b. examining two similar liquid mixtures visually and with a laser pointer,
    c. noticing that the beam from the laser is visible only in the colloid,
    d. hypothesizing the reason for the differences in the two mixtures, and
    e. revising their ideas after they read and explore more about colloids.

2. begin to apply the processes of flocculation to a water treatment system. They will demonstrate their ability by relating the laboratory model of flocculation to a water treatment system.

3. determine the appropriate dose of flocculant for their system.
   They will demonstrate their ability by
   a. designing an investigation to find the appropriate dose,
   b. conducting the investigation,
   c. analyzing the results of their investigation, and
   d. choosing and justifying the appropriate dose based on their results.

4. Synthesize their understanding about the processes of flocculation and sedimentation.
   They will demonstrate their ability to synthesize by
   a. identifying all possible ideas for using or not using the process in their water treatment system,
   b. listing all considerations for each possibility,
   c. identifying methods for determining the feasibility of their ideas, and
   d. identifying considerations for choosing the best solution.

Materials: (per station)
1 test tube with colored water
1 test tube with water and gelatin the same color as the colored water
test tube rack
laser pointer
4 hand lenses
clear drinking glass
water with a few drops of milk (place in drinking glass)
glass of whole milk
vinegar
lemon juice
3 L contaminated water
alum stock solution (10 g alum/1L distilled water)
1 L distilled water
graduated cylinder (1 L or 500 mL)
stir stick
pipette, 10 mL
graph paper (can be one page per student or one page per group)
turbidity tester pH
meter
spectrophotometer

Advanced Preparation

Coagulation/Flocculation Station Set-up

1. Prepare two test tubes in advance for this station. Add warm water with red food color to one and gelatin dissolved in warm water to the second tube (keep the gelatin in liquid form). Any color will work as long as both tubes are the same color and appear identical. Place the tubes in a rack and place on the table near Step 1.

2. Place a laser pointer and 4 hand lenses at the station.

3. Step 2 at this station will be on a computer. Bring the information up on the screen and ensure that the computer is connected to the Internet.

4. Step 3 should have a drinking glass with diluted milk available (1-2 drops per 400ml). Also place a glass of whole milk near this step.

5. Place a copy of the protocol notebook at the station.

6. Set up an area for students to conduct the jar test. You can purchase a jar test apparatus from VELP (http://www.neutecgroup.com) or request the equipment on loan from Texas Tech T-STEM center. An alternate method is to use 4 or more magnetic stirrers with adjustable speeds. If you choose to use this method, take time before your students use them to determine the proper setting for RPMs of 20, 100, and 30 RPMs as described in the Jar Test Protocol. Mark these speeds on your magnetic stirrers. The exact RPM is not as important as it is for all four stirrers to be spinning at the same rate.

7. Students will be asked to measure turbidity before and after the jar test. A turbidity test kit from a water chemistry set will work fine. Alternatively, you may want to use a spectrophotometer for this test. If you choose to use the spectrophotometer, include a protocol for using the device in the protocol notebook.

Teacher Support for the Student Activity

Remind students that they must record all their ideas and responses in their journals. The icon  will remind students that there is something to record in their journals.

In Step 1, students will explore two test tubes filled with colored liquid. They appear identical but with closer observation with a laser pointer, students see a difference. The purpose if this step is to get students thinking of particles that might be suspended in the liquid. These particles are not visible to the unaided eye but when a laser beam is shined through the liquid, the particles are large enough to reflect the light making the beam of light visible. Gelatin is a colloid and the particles, while very small, are large enough to reflect the light from the laser pointer. Therefore, the beam from the pointer is visible. The scattering of light by very small particles is called the Tyndall effect. Provide resources if you want your students to investigate this effect further.

***Answer to* Think about this #1:**
Student answers will vary but they are likely to say there is something very small that reflects the light in test tube #2. Do not expect complete answers at this point; they will have opportunity to revise their responses.

Students learn about colloids and colloidal particles as well as various examples in Step 2. Students will need to access this step electronically because of links to electronic media related to the water treatment process. Through reading and these electronic resources, students learn about the processes of flocculation and sedimentation.

***Answer to* Think about this #2:**
Students should revise their answer to #1 by adding information they have learned in this step. Things they may add include, colloid size, examples of colloids, and that the liquid was a colloid with larger particles that can reflect light. Students should make their revisions in a different color. This strategy will help you and the student monitor their progress.

In Step 3 students must apply what they have learned to the colloid at this step. They must confirm that milk is a colloid and design a way to coagulate the colloid. Students can verify that milk is a colloid by placing a few drops of milk in a glass of water and checking for the Tyndall effect. The beam from the laser pointer will be visible through the diluted milk. Students are challenged to design a way to coagulate the milk. They learned in the previous step that changing the pH of the mixture may cause the colloids to come together and form a floc (flocculation). You may have to ask probing questions to get students started. Ask question such as, How could you change the pH of the milk? What common substances do you know that are acids or bases? What would you like to try? Have vinegar and alum solution available. Students will need your approval before carrying out their investigation. Once they have gotten results and recorded them in their journals, they must answer several "*Think About This"* questions.

These questions are designed to guide students into making good decisions when designing their water treatment system. Some students may think that the flocculation and sedimentation processes are unnecessary. However, they should realize through thoughtful consideration of these questions that without this step in the treatment process, colloidal particles will not be removed. And, if they do not allow the floc to settle and pass the sample through the filter too soon, the filter will soon become clogged.

***Answer to* Think about this #3-6:**

3. ***Pouring milk through a filter will not remove the protein because the protein molecules are too small. If students do not know for sure, allow them to test their ideas.***
4. ***A filter would remove the large clumps of coagulated material. However, this would clog and damage the filter.***

5. ***Students should remember the sedimentation step from the computer activity in Step 2. They could allow the coagulated material to settle and then drain off the liquid from the top.***
6. ***This question is designed to see if your students make the connection from what they learned with the milk example to a new situation—one that is real in a water treatment plant. The clay particles can be removed by adding a substance (flocculant) to the water so that the surface charge is destroyed or neutralized. The clay particles could then clump together and form a floc. The floc could then settle to the bottom (sedimentation) and the clear water removed from the top. Watch for answers that say the clay particles can be removed by filtration. The filters used in water treatment plants have pores too large to remove the colloid particles. Students must understand that the colloid particles in water cannot be removed by simple filtration in a water treatment plant. Some students may respond that you could just find a filter with smaller pores. If they have not been to the filtration station they may not understand that the smaller the pores the slower the water passes through the filter. This prohibits water treatment plants to use filters with very small pore size.***

In the fourth step at this station, students will conduct a jar test to determine the proper coagulant dose (alum) for the water sample. Too little alum will not remove all the colloid and too much alum will add to the chemical waste of the process. Green engineers want to use the least amount of chemical possible to be effective. Students use varying amounts of alum, combine their data with class data, and plot their results. They will be able to tell from the graph the lowest dose that produces the least turbidity and make decisions about their water treatment design from their data.

In the final step of this station, Step 5, students synthesize what they have learned. The students should review the documents for the Research phase of the FRAME engineering design model. The *Think about this* questions guides them through the final portion of this phase as they consider all of the possibilities for this phase of the water treatment process. Ensure that students are concentrating only on the flocculation and sedimentations portion of the water treatment process.

***Answer to* Think about this #7-10:**

Responses will vary. Students will demonstrate their understanding of the overall process of flocculation and sedimentation in their final design. As green engineers they should determine a minimal dosage of alum that will provide maximum results in removing colloids as well as conditions that are most effective for flocculation. Specifically, they should recognize the role of pH in the effectiveness of their design. The alum is insoluble in water at a pH of 8, and it will provide optimal results in altering the surface charge of the colloids to promote flocculation. A final design should communicate the sequence of steps, the materials and the conditions for maximum results that meet green requirements.