From Turbid to Clear: How Flocculation Cleans Up Drinking Water

https://www.sciencebuddies.org/science-fair-projects/project-ideas/EnvEng_p039/environmental-engineering/clean-drinking-water-flocculation (http://www.sciencebuddies.org/science-fair-projects/project-ideas/EnvEng_p039/environmental-engineering/clean-drinking-water-flocculation)

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Experimental Procedure

Building Your Turbidity Meter

In this section, you will assemble a circuit on a **breadboard**. If you have never used a breadboard before, you should refer to the Science Buddies resource reference How to Use a Breadboard (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard) before you proceed. You can follow a step-by-step slideshow (#) that will show you how to put components in the breadboard one at a time. Alternatively, Table 1 lists each component and its location on the breadboard. **Important**: Read the following notes before you proceed.

- Resistors are marked with colored bands. These colors *do* matter. Make sure you pick the right resistors for each step, according to the markings.
- It matters which direction some of the components are facing. Make sure you read the slideshow captions for any special notes about inserting each part.
- This section only shows you how to assemble the circuit. For a detailed explanation of how the circuit works, see the Help (#help) section.

Slideshow with step-by-step instructions viewable online.

Part name	Picture	Breadboard Symbol	Location
9 V battery			Red wire to (+) bus Black wire to (-) bus
Photoresistor			F24, F26
White LED			Long lead to B17 Short lead to D16
Jumper wires (3)			J24 to multimeter J26 to multimeter A17 to (+) bus
220 Ω resistor			E16 to (-) bus

Table 1. Components for the turbidity meter circuit (Image credits: Jameco and Fritzing).

Testing Your Turbidity Meter

After you have finished building your circuit, testing the turbidity meter is necessary to ensure that all the electronic components are connected correctly and your device works as expected. *Note*: Stray light will cause problems and may result in fluctuating data. Perform the readings in a dimly lit room if stray light is a problem, and make sure to always place the cuvettes into your device the same way. If the sides of your cuvettes are not all clear but two of them are grooved or frosted, make sure that the clear side is always facing towards the LED and the frosted or grooved side is facing towards the photoresistor. Place a bowl or cardboard box upside-down over your breadboard during measurement to block out surrounding light. If you get fluctuating data, make sure to check if your cuvettes are free of smears or dirt on the outside and that there are no air bubbles sticking to the sides.

1. Cut a small piece of construction paper and roll it into a tube that just fits on the head of the LED. The tube length should be about 2 cm. Place the tube on the head of the LED and attach it with some tape so it is not able to slide off.
2. Place an empty cuvette upside-down over the photoresistor. Make sure that for this cuvette the clear side faces towards the front of the photoresistor. Bend the photoresistor leads as needed to fit underneath the cuvette. Use tape to hold the cuvette over the photoresistor in place. But do *not* block the light path!
3. The light path from the LED and the tube should be exactly aligned with the height of the photoresistor, as shown in Figure 4. Bend the wires on the LED and photoresistor for adjustment, if needed.

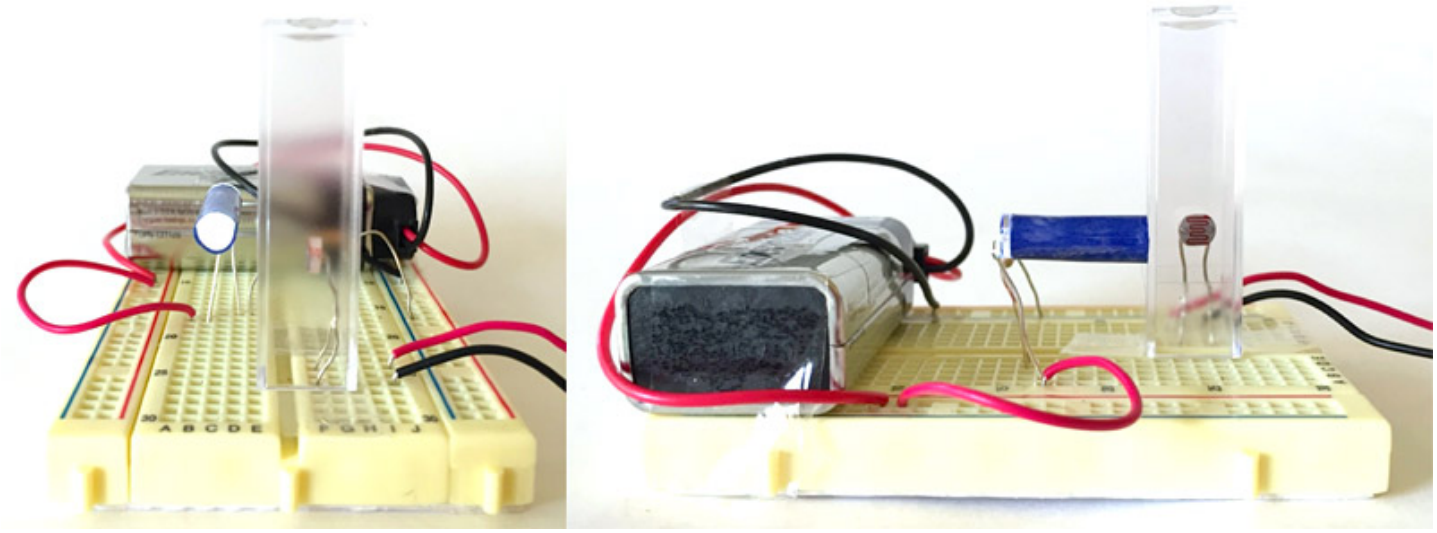

Figure 4. The light path of the LED should be directly aligned with the height of the photoresistor.

4. Set up the multimeter to measure the resistance of the photoresistor.
    a. Plug the black multimeter probe into the port labeled COM.
    b. Plug the red multimeter probe into the port labeled VΩmA.
    c. Turn the dial setting to 200 kΩ.
    d. Turn the multimeter's power switch ON.
    e. Make sure you remembered to use the alligator clips to attach the multimeter probes to the jumper wires connected to the photoresistor coming from J24 and J26.
5. As you connected the jumper wire from A17 to the power (+) bus already, your LED should still be turned on.
6. Cover the circuit (but not the multimeter) with a bowl to block ambient light.
7. Read the resistance across the photoresistor and record it in your lab notebook.
    a. Note the units of the resistance. A "k" indicates kilo-ohms (kΩ).
    b. If your multimeter screen displays a "1.", that means the resistance is too high for the dial setting. Turn the dial up to the next highest range (for example, from 200 k to 2000 k) and check again.
    c. If this is your first time using a multimeter, refer to the Science Buddies resource How to Use a Multimeter (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter), specifically the section How do I Measure Resistance? (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter#qmultimetermeasureresistance), to learn more.
8. Remove the bowl and turn off the LED by removing the jumper wire from the power (+) bus.
9. Cover the circuit with the bowl again. In the dark, the resistance should be in the mega-ohm range. Remember that you may need to adjust the dial setting to get a measurement. Record the resistance in your lab notebook.
10. Remove the bowl and turn off the multimeter to conserve battery power.

Calibrating Your Turbidity Meter

Now that you have set up and tested the turbidity meter, the next step is to make the **standard** solutions to calibrate it. You will make a series of dilutions containing different amounts of soil, or total suspended solids (TSS), with known concentration (as shown in Figure 5) and measure them with your turbidity meter to create a **calibration curve**. Each dilution is made by consecutively diluting your turbid water by half.

Figure 5. Standard solutions with different amounts of total suspended solids for calibration of the turbidimeter.

1. Gather some dry soil from your garden or another source. Use the fine-mesh sieve to filter out larger materials, such as stones or sticks and leaves. You will need about 15–20 g of sifted soil.
2. Transfer the sifted soil into a mortar. Grind the soil really well until you have a very fine, homogeneous soil powder.
3. Take seven clean plastic cups and label them #1–7 with your permanent marker.
4. Use the measuring cup to pour 100 mL of tap water into the first cup (#1). Add 50 mL of water into cups #2–7 each.
5. With the digital scale, weigh 0.5 g of your ground, very fine soil, and mix it into cup #1. Stir with a clean spoon until you get a nice turbid solution. The solution should stay turbid for a while once you stop stirring, but it is fine if some of the soil particles settle to the ground immediately.
6. Use the measuring cup to pour 50 mL from cup #1 into cup #2 and mix with a clean spoon. Make sure that you stir cup #1 just before you pour some of it into the measuring cup so that you also transfer the suspended solids that have settled from cup #1 to cup #2.
7. Thoroughly rinse the measuring cup and mix 50 mL from cup #2 with the water in cup #3. Again, make sure to stir cup #2 just before you transfer the liquid so the particles that tend to settle on the bottom can also be transferred.
8. Repeat the two-fold dilutions for cups #4–7.
9. Label seven clean cuvettes #1–7 (at the very top of the cuvette to not block the light path with your writing) and transfer the seven standard solutions into the matching cuvette using a fresh or rinsed transfer pipette for each one. Make sure you get a good representative sample into the cuvette by stirring the standard solutions again before transferring them into the cuvette. *Note*: The cuvettes hold approximately 3 mL of solution.
10. Set the multimeter to read resistance again. Remember that you might have to adjust the range as you take different readings.
11. Place your first standard sample between the white LED and the photoresistor, as shown in Figure 6. Before you put the standard in the turbidity meter, cover the cuvette with your thumb and shake it really hard to get all the settled particles distributed within the solution. The little tube on the LED head should touch the cuvette and should be positioned approximately in the middle of the cuvette. If your cuvettes have frosted or grooved sides, make sure this side is facing toward the photoresistor and the clear side is facing toward the LED.

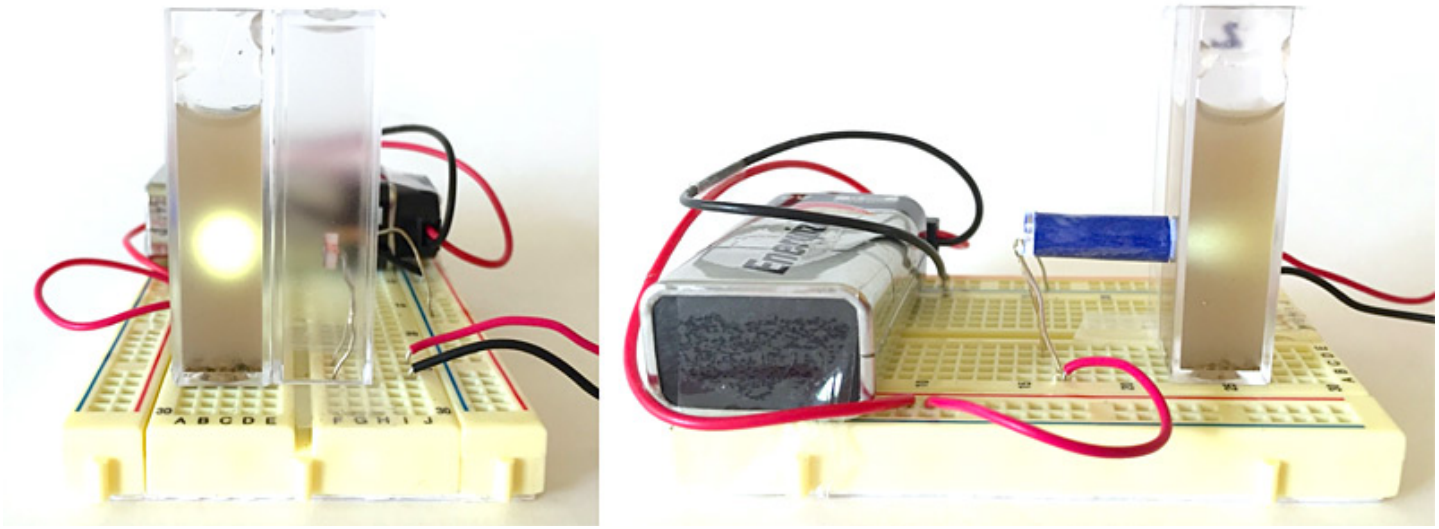

Figure 6. Setup of the turbidity meter for measuring your standard solutions and samples. Note that in these pictures, the LED is switched on, but the setup is not covered with a bowl yet.

12. Plug in the jumper wire from A17 into the power (+) bus to turn on the LED. Cover the breadboard with a bowl and slowly count to 5. Then read the resistance on the multimeter and record the data in your lab notebook. As for your standards and samples some of the particles tend to settle to the bottom once you shake the solution, the turbidity will change over time. Therefore, it is important to read the resistance values for each standard and sample at the same time after shaking it. If you find that your data fluctuates a lot, try to reduce the amount of ambient light by going to a darker room, or wait until nighttime to do your experiment. *Note*: Solutions that are very clear, such as the standards with low concentrations of suspended solids, tend to result in more data fluctuations.
13. Remove the first standard and replace it with the cuvette containing the next standard solution. Shake the cuvette again before placing the standard in your device. Cover the breadboard with the bowl, and again slowly count to 5. Then write down the resistance for this solution. Continue the measurements for each of your seven standards.
14. Repeat the measurements with the entire set of standards two more times.
15. Make a data table in your lab notebook showing the dilutions and concentrations of the total suspended solids in all your standards (#1 = 5 g/L, #2 = 2.5 g/L, etcetera) together with all three recorded resistance measurements for each solution. The resistance should be higher as the solutions get clearer.

Conducting Your Flocculation Experiment

Now that you know how the turbidity of your sample—or the amount of suspended solids in your water—relates to the resistance measured with your turbidity meter, you can monitor the cleanup of your murky water sample during your jar test. You will test six different flocculant concentrations to find out which one of them results in the best cleanup process.

1. Build a stirring device that allows you to simultaneously stir six samples.
    a. Line six cups up next to each other and label them #0–#5.

b. Take a long stick and, with tape, attach 6 spoons to the stick. Position the spoons so that each spoon fits into one of the cups once you hold the stick above the cups, as shown in Figure 7.

Figure 7. Stirring device that allows for simultaneous stirring of six sample solutions. Note that this image shows glass Mason jars, but you can also do the experiment in plastic cups.

2. Take one of your bowls and fill it up with 1,000 mL of tap water using the measuring cup.
3. Use the digital scale to weigh 5 g of your ground soil and mix it into the bowl with water.
4. Dispense 150 mL of this mixture into each of the six cups, making sure that you stir the solution with a clean spoon each time, just before you transfer the solution into a new cup, to make sure to also transfer the particles that tend to settle on the bottom.
5. Prepare your alum flocculant solution.
    a. Fill the second bowl with 1,000 mL of tap water using the measuring cup.
    b. Weigh 7.5 g of alum using the digital scale and add it to the bowl with water. Stir the solution with a spoon until everything is dissolved.
6. Line up all your cups containing the turbid water next to each other. With a permanent marker, draw a line on each cup, halfway between the bottom of the cup and the top of the solution, as shown in Figure 8. *Note*: It is important to extract all your samples from the same depth in your filled water cups (from where you made the line on the jars or cups) to be able to compare the flocculation and settling process in each cup.

Figure 8. Turbid water samples before adding different amounts of flocculant (alum). Note that although this image shows glass Mason jars, you can also use plastic cups for your experiment.

7. Pre-label one set of six clean cuvettes for each of your sampling time points (0 minutes, 2 minutes and 15 minutes). On each cuvette, first write the cup number (#0–#5) and the time point ("0", "2," and "15"). Remember to only write on the very top of the cuvette. Put the cuvettes aside until they are needed.
8. Label six transfer pipettes #0–5 and use one for each cup to transfer about 3 mL of liquid from each cup into the first set ("0") of labeled cuvettes. Make sure to stir the solutions (you can use the transfer pipette for that) first before you take the sample. When taking samples, make sure the tip of the transfer pipette lines up with the permanent marker line on the outside of the cup. Put the filled cuvettes aside for now and make sure you do not accidentally knock them over.
9. Rinse the transfer pipettes with tap water by sucking up and squirting out tap water a couple of times.
10. Add different volumes of your prepared alum solution to each of the cups, according to Table 2, resulting in six solutions with a different alum concentration in each.

Cup number [#]	Volume of alum solution added [mL]	Concentration of alum [mg/L]
0	0	0
1	0.5	25
2	1.5	75
3	2.5	125
4	3.5	175
5	4.5	225

Table 2. Added amounts and concentration of alum in each cup.

11. Set your timer for 2 minutes and use your self-made stirrer to stir each cup simultaneously for 2 minutes, as fast as you can, but being careful not to knock the cups over.
12. Stop stirring after 2 minutes and set your timer again for 2 minutes. Make sure *not* to disturb the solutions anymore once you have stopped stirring. Depending on the added alum concentrations, microflocs might be forming in your solutions and start settling down.
13. Prepare your second set of labeled cuvettes ("2") and after 2 minutes of settling time in the previous step, use your rinsed transfer pipettes to take a sample of each cup. Do not forget to take the sample at the same depth (where you put the permanent marker line). Transfer about 3 mL of sample from each cup into the labeled transfer pipettes. This time, do *not* stir the solutions! Put the full cuvettes to the side until measurement.
14. Set your timer again for 13 minutes and start it. Observe the flocculation process in each cup. Prepare your third set of labeled cuvettes ("15") and after 13 minutes use your rinsed transfer pipettes again to take a sample of each cup. Do not forget to take the sample at the same depth as before (where you put the permanent marker line). Transfer about 3 mL of sample from each cup into the labeled transfer pipettes. Again, do *not* stir the solutions! Put the full cuvettes to the side until measurement.
15. You can leave the cups for further observation, although you will not take any more measurements.

Measuring Your Samples

1. Get all your samples from each time point ready ("0", "2," and "15").
2. Make sure you are in a dark room with minimal light and have your turbidity meter ready with the multimeter leads still attached to the jumper wires.
3. Set the multimeter to read resistance again. Remember that you might have to adjust the range as you take different readings.
4. Plug in the jumper wire from A17 into the power (+) bus to turn on the LED if it is not turned on yet.
5. Start with measuring the first sample solution from time point "0". Place the cuvette in between the white LED and the photoresistor, as you did with the standards before. Remember to face the clear side of the cuvette towards the LED and the frosted or grooved side towards the photoresistor. Before you put the sample in the turbidity meter, cover the cuvette with your thumb and shake it really hard to get all the settled particles mixed in the solution. Cover the breadboard again with the bowl and slowly count to 5. Then write down the resistance for this sample. Continue the measurements for each of your samples of time point "0". Then repeat the measurements with the entire set of samples two more times.
6. Continue measuring the next time point samples ("2") and then proceed to the last time point samples ("15"). Make sure to also repeat the measurements with all samples for each time point two more times. *Note*: Remember that very clear solutions, such as sample solutions with low concentrations of suspended solids, tend to result in more data fluctuations.

Analyzing Your Data

1. Open a spreadsheet and enter the data (the TSS concentration [g/L] and resistance values of your standards) for your calibration curve. Calculate the average for your three resistance readings for each standard.
2. Graph the average resistance of your three readings on the y-axis versus the TSS concentration of the standard solutions in g/L on the x-axis. You will notice that the relationship between measured intensity of scattered light (or the resistance) and concentration is nonlinear. You can linearize the data by performing a base-10 logarithmic transformation of your data. Simply graph the average resistance data on the y-axis versus the $\log_{10}$ of the total suspended solids concentration of your standards on the x-axis. Now you should get a linear calibration curve.
3. Add a trend line to the linearized data and display its equation and its correlation factor R^2.
4. For each time point (0, 2, and 15 minutes), enter your resistance data into the spreadsheet for each cup and calculate the average of your three readings for each sample.
5. Using your calibration curve, determine the concentration of total suspended solids in each of your sample solutions for each time point. Remember that the results from your calculations will be the log(TSS). To get the real concentration of TSS, you have to convert your result from log(TSS) to TSS by taking your calculated result from the calibration curve and raise 10 to that number.
6. Make a graph that shows the settling time (0, 2, and 15 minutes) on the x-axis and the calculated concentration of total suspended

solids (in g/L) on the y-axis. Do you see that the amount of total suspended solids changes over time?

7. Calculate the TSS decrease over time for each of the cups/alum concentrations in percent. The TSS concentration at time point 0 will be 100%. To calculate the percentage for each of the following time points, use Equation 1, as follows:

Equation 1:

$$TSS\ \ concentration\,(\%)\ \ =\ \ \frac{TSS\ concentration\ at\ time=2\ \ or\ \ time=15}{TSS\ \ concentration\ at\ time=0}\ \times\ 100$$

8. Finally, make a bar graph showing the alum concentration added to each jar on the x-axis and the percentage of TSS on the y-axis for each time point. How do the graphs compare for each alum concentration and the control without alum addition? From this graph, can you tell which alum concentration is the optimal one? Do you think increasing the alum concentration even more would make sense?

Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at https://www.sciencebuddies.org/science-fair-projects/project-ideas/EnvEng_p039/environmental-engineering/clean-drinking-water-flocculation#help.