Filtration of Water Lab Exercise

Objective

- Investigate how the particle size of activated carbon affects drinking water filtration efficiency.

Purpose/Problem

- Do you filter your tap water before drinking? Many commercials claim these filters make your drinking water cleaner and safer. But what, exactly, are these filters doing and is the water cleaner afterwards? The cleaning power comes from their filling material, called activated carbon. It exists in all kind of forms: powder, granules, foams, and blocks. Do you think it matters what type of activated carbon is inside the filter? In this activity you will investigate whether larger or smaller particles of activated carbon work better for cleaning drinking water—with results you can see!

Introduction **{Students are to write their OWN introduction for the lab report and not a carbon copy of what is provided below. Students are to conduct additional research AND more importantly, incorporate the relationship between water filtration and global health. What are some statistics about clean water across the globe? What are the health impacts of not having clean water available? What are examples and statistics of those suffering from disease due to not having clean water available?}**

Clean water is an essential part of life. Just think about how often you use water every day—for cooking, drinking, washing your clothes and dishes, brushing your teeth, or showering. You wouldn't want to do this with dirty water, right? **Filtration** is one important step in water cleanup. During the filtration process, particles or impurities such as chemicals and bacteria are separated from the solution that is filtered. The method of separation can be mechanical, physical, chemical or even biological. To find out how water filters work, it is probably best to have a look inside the filter. Most of the filters that are used for home water treatment are **carbon filters**. That means the material inside the filter is carbon or a special form of it, called **activated carbon** or **activated charcoal**, which is shown in Figure 1.

Figure 1. Activated carbon in powder and block form (Image credit: by Ravedave, via Wikimedia Commons)

What makes activated carbon special is that it is a very porous form of carbon—almost like a sponge. It has many tiny microscopic pores that can soak up water or gases. Also, the surface of activated charcoal is not smooth—if you look under the microscope you see that the particles have a very crumbly shape as shown in Figure 2. All these little micropores, together with its rough surface, create a huge **surface area** for each particle. About five teaspoons (10 grams) of granular activated carbon has a surface area that is approximately the area of a football field!

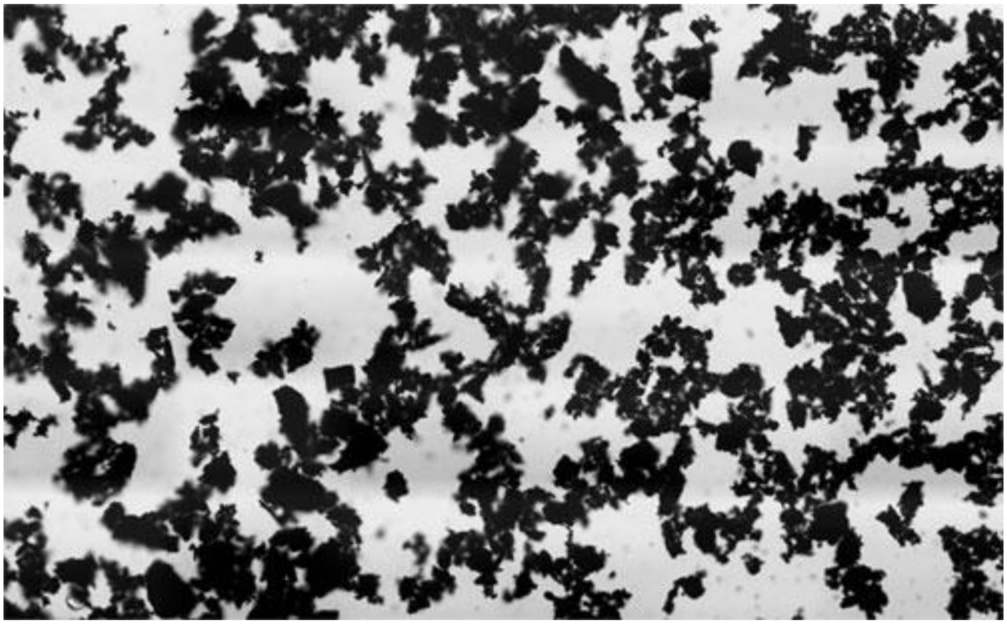

Figure 2. Activated charcoal particles viewed under a microscope (each particle is about 0.1 mm wide). The crumbly particle structure and shape result in a large surface area for each particle (Image credit: Zephyris, via Wikimedia Commons).

This massive surface area gives activated carbon unique properties. When water or liquid travels through the porous structure of the filter, impurities (such as small amounts of chemicals or metals) can be removed by a process called **adsorption**. Adsorption occurs when compounds physically or chemically adhere to the carbon surface. Physical or chemical trapping happens due to **van der Waals forces**, weak forces that exist between molecules or particles that can be attractive or repulsive, as well as to chemical bonding on the carbon surface. This is why the surface area, or the **surface area to volume ratio**, of the activated carbon matters. The more surface area (area exposed to the surroundings), the more possible bonding sites there are for contaminants. If all the bonding sites are taken up, then the impurities remain in the water and it is time to replace your water filter.

Activated charcoal can come in many forms and **particle sizes** (some of them are shown in Figure 1). The two types you will be using in this experiment are the granular and powder forms. Granular carbon can be compared to small pebbles, while powdered carbon can be compared to fine sand. Looking at Figure 3, you can think of the left cube as the granulated carbon and the smaller cubes as the powdered carbon. They both have the same volume (a total of 8 small cubes), but the surface area exposed to the surrounding is much larger with the 8 individual cubes compared to the one large cube. Therefore, the granular form has a smaller surface area to volume ratio than the powder form.

Figure 3. Although both the cube on the left, and the 8 individual small cubes on the right, have the same volume, the total surface area is much higher for the smaller cubes than the large one. This means smaller particles have a higher surface area to volume ratio than bigger particles.

Besides the surface area to volume ratio, the time the water spends in contact with the activated carbon is also an important factor that determines the efficiency of the filtration process. The longer the **contact time** or the slower the flow rate of the water through the filter, the more adsorption can take place. You will see for yourself in this project when you clean up colored tap water with activated carbon. Which material do you think will be better to clean up your water, powdered or granular carbon?

Terms and Concepts

- Filtration
- Carbon filter
- Activated carbon, or activated charcoal
- Surface area
- Adsorption
- Van der Waals forces
- Surface area to volume ratio
- Particle size
- Contact time

Additional Pre-Lab Questions {Please also use the questions provided in addition to those provided on the course website}

- What are typical uses of activated carbon?
- Why does the form of activated carbon and its particle size matter for filtration?
- How do carbon filters clean contaminated drinking water?
- Can you think of other processes or reactions in which the particle size or surface area to volume ratio matters?

Materials and Equipment {Please remember, within the report, that materials, equipment and procedures should be written in essay format and not bullet format as seen below. Please see course website for information in regard to completion of lab report}

- Granulated activated charcoal; available from Amazon.com
- Powdered activated charcoal; available from Amazon.com
- **Plastic cups** (no lids necessary), **transparent** **20 oz (90, 30 per trial);** available from Amazon.com
- Food color (green, blue or red work well); available from Amazon.com
- Spoon
- Tap water
- Coffee filters (bleached or unbleached), size **4 for 20 oz cups (108, 36 per trial**)
- Rubber bands (9)
- Measuring cup
- Timer
- Paper towels
- Scale that can measure in 0.1 g increments. A digital scale that would be suitable is the Fast Weigh MS-500-BLK Digital Pocket Scale; available fromAmazon.com.
- Permanent marker
- Optional: Camera (phone or digital)
- Optional: Computer with access to the internet, and permission to use it.
- **Lab notebook {composition book}**

Experimental Procedure **{Please remember that within the report, the procedures are not to be written word for word, and in bullet format, as shown below. Procedures should be written in essay format, third person and in past tense. Please see course website for information in regards to lab reports.}**

In this experiment you will filter three water samples with different "contaminant" (food color) concentrations using three different filtration conditions (granular activated carbon filter, powdered activated carbon filter and no carbon filter). Once you have completed the filtration, you can assess the filtration efficiency of each filter by looking at the color change of your samples.

Preparing Your Samples and Filters

In this section, you will prepare a total of 21 cups: 3 cups with different food color solutions, 9 cups with either no carbon, granulated carbon, or powdered carbon (3 of each type), and 9 filtration cups (empty cups with filters attached).

1. First, you will prepare the water samples that you are going to filter. You will use food color as a model contaminant that needs to be removed from the water. Prepare three food color solutions, each with a different dye concentration.
    a. With a permanent marker, label three cups, one for each dye concentration: 0 drops per cup of liquid, 2 drops per cup of liquid and 5 drops per cup of liquid.
    b. Measure 2 cups (about 500 mL) of tap water into each plastic cup using the measuring cup.
    c. You will only add food color to two of the three cups as shown in Figure 4. The first cup (*0 drops per cup of liquid*) will remain colorless. As you have 2 cups of liquid in each of your cups, you have to add 4 drops of food color to the cup that you labeled with *2 drops per cup of liquid* and 10 drops of food color to the cup that you labeled *5 drops per cup of liquid*.
    d. Stir each of the solutions with a clean spoon to disperse the food color evenly.

Figure 4. Prepared water samples with different concentrations of green food coloring for the

carbon filtration experiment (from left to right: 0 drops per cup of liquid, 2 drops per cup of liquid and 5 drops per cup of liquid).

2. Next, prepare the activated carbon for your filter. You will test three different experimental conditions (granular activated carbon, powdered activated carbon and no activated carbon) for each of the dye concentrations.
    a. As you will test all three dye concentrations, you have to label 3 cups for each form of carbon you test. You can make up your own labeling abbreviations such as "PC" for powdered carbon and "GC" for granulated carbon. Your label should tell what form of carbon and what dye concentration you will use (0, 2 or 5 drops per cup of liquid) for that cup. At the end, you should have 9 labeled cups.
    b. Use a scale to weigh out **3 grams** of granular activated carbon into each cup that you labeled with granular carbon. Then **add 3 grams of powdered activated carbon** into each cup with the respective label. The remaining 3 cups (no activated carbon) stay empty. *Note*: Avoid breathing in the activated carbon powder and try not to disperse too much of the powder into the air.
    c. You should have 3 empty cups and 6 cups filled with activated carbon: 3 cups with the powdered form and 3 with the granular form.
3. Next, you will set up filters for the different forms of activated carbon and dye concentrations.
    a. Label 9 cups in total, one for each testing condition. Again, make sure that your label is specific to the type of activated carbon and the dye concentration that you are going to test.
    b. Take 4 coffee filters and stack them into each other. As shown in Figure 5, press the filters into the top of a cup, fold their edges over the cup's rim, and secure them with a rubber band.
    c. Repeat step b. for the remaining filtration cups.

Figure 5. Using 4 layers of coffee filter, prepare a basket shaped filter inside each filtration cup and secure it with a rubber band.

Filtering Your Samples

In this section, you will prepare an additional 9 cups for your colored water samples. When starting your filtration process, you should have a set of 9 cups for each experimental condition (27 cups total).

1. Before you start the filtering process, prepare your water samples for each filter using the water samples you prepared in step 1 of "Preparing Your Samples and Filters".
    a. For each experimental condition (granular activated carbon, powdered activated carbon and no activated carbon), label 3 fresh cups with *0 drops per cup of liquid*, *2 drops per cup of liquid* and *5 drops per cup of liquid*.
    b. With a measuring cup, add 0.5 cups (about 120 mL) of the dye solutions that you prepared in step 1 of "Preparing Your Samples and Filters", to each of the cups with the respective label. *Note:* You will have 0.5 cups dye solution left over that you can use at the end of the experiment for color comparison.
    c. Before you switch to the next dye concentration, rinse out the measuring cup and clean it with a paper towel.
    d. Do *not* add the solutions to the prepared charcoal cups yet!
2. Arrange all your prepared cups as shown in Figure 6. For each experimental condition and dye concentration, place the colored water sample, the activated carbon and the filtration cup next to each other. You should have a set of 9 cups for each of the 3 experimental conditions (27 total).

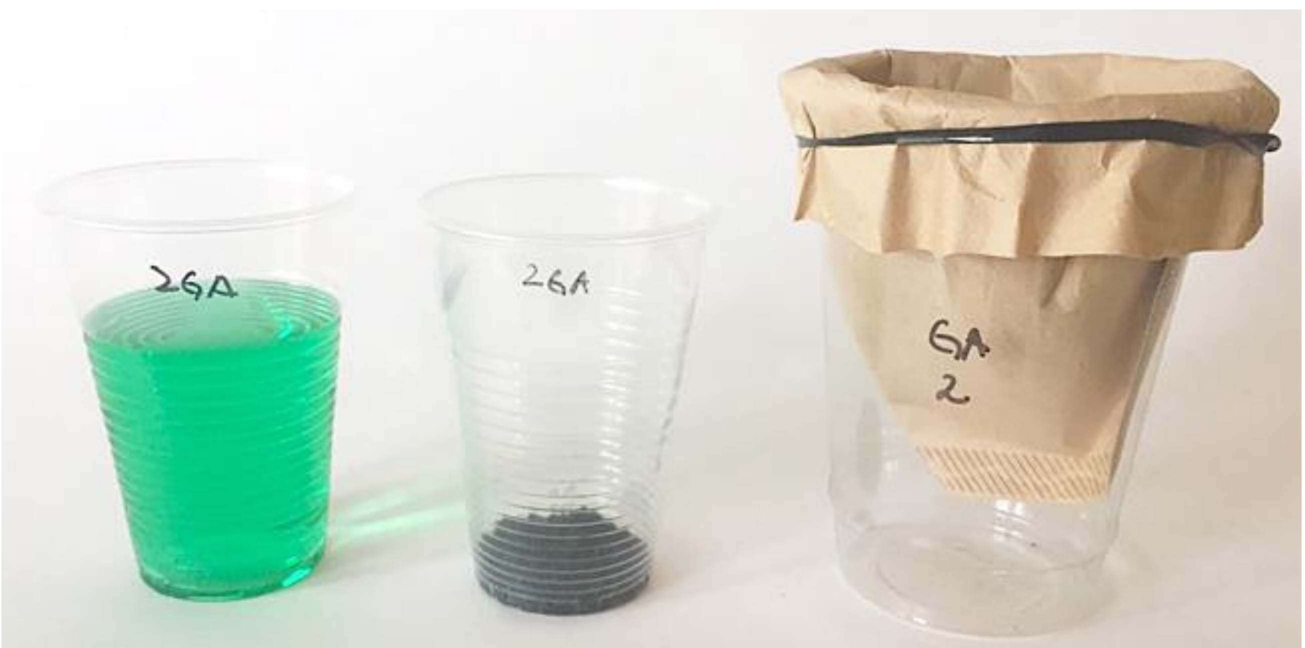

Figure 6. Arrange all prepared cups so that the colored water sample, the activated carbon and the filtration cup for each experimental condition and dye concentration are placed next to each other. In this image, the cups for the filtration experiment with a dye concentration of 2 drops per cup of liquid ("2") and granular activated carbon ("GA") are shown.

3. Before you start with your filtration experiment, prepare a data table such as Table 1 in your lab notebook. Copy this table into your notebook three times, once for each type of carbon (granular activated carbon, powdered activated carbon, no activated carbon).

Carbon type:		Color rating after treatment			
Dye concentration [drops/cup of liquid]	Color rating before treatment	Trial 1	Trial 2	Trial 3	Average
0	0				
2	7				
5	10				

Table 1. Data table in which to record your filtration results.

4. You will rate the color of your water samples on a scale from 0–10, where 0 is totally clear (the cup on the left in Figure 4) and 10 is the darkest (the cup on the right in Figure 4). You will have to choose a number to assign to the intermediate cup, which may vary slightly depending on the type or color of food color you use. We chose to assign a value of 7 to our 2 drops/cup of liquid sample, since it is fairly dark.
5. Assess all your water samples before the filtration. Within a specific dye concentration, they should all look the same. As mentioned in step 4, they all will start out with an assigned color number before filtration. These will be your starting (before filtration) values.
6. If you have a camera available, **take a photo of all your solutions before starting the filtration.** This will be **helpful for your display board.** Make sure that all the pictures are taken with the same lighting, background, and camera settings (it is probably best to use a white background) so you can compare them to each other. *Note*: You can use the left-over dye solutions that you prepared in the beginning as a color reference for "before treatment" samples.
7. Continue with the filtration. You can do the following steps either back-to-back or set them up and run them at the same time.
    a. Start with the filtration experiment using granular activated carbon.
        i. Pour each concentration of the prepared dye solutions into the respective cups containing the granular activated carbon that you prepared in step 2 of "Preparing Your Samples and Filters".
        ii. Set your timer to 10 minutes and quickly stir each solution with the activated carbon using a clean spoon.

iii. After 10 minutes, pour the water and carbon mixture into the filters that you prepared in step 3 of "Preparing Your Samples and Filters," and let the water seep through the filters. *Note*: Make sure that the water drains out of the filters completely and collects in the cup below the filter. There should not be any water remaining in the filter. If the water level reaches the bottom of the filter once it has seeped through, either choose a larger cup or use shorter, basket shaped coffee filters instead of the longer, conical ones.

b. Next, continue with the filtration experiment using powdered activated carbon.
   i. Slowly pour each concentration of the prepared dye solutions into the respective cups containing the powdered activated carbon that you prepared in step 2 of "Preparing Your Samples and Filters". *Important*: Pour slowly so you avoid creating a lot of powder dust in the air.
   ii. Set your timer to 10 minutes and quickly stir each solution with the activated carbon using a clean spoon.
   iii. After 10 minutes pour the water and powdered carbon mixture onto the filters that you prepared in step 3 of "Preparing Your Samples and Filters" and let the water seep through the filters. Make sure that no water is staying inside the filters.

c. For the filtration experiment using no activated carbon, pour each of the prepared water samples onto the filtration cups prepared for this condition in step 3 of "Preparing Your Samples and Filters". Again, let the water seep through the filters completely.

8. Let the solutions in each cup seep through the 4 layers of coffee filter. Write down your observations about the collected water samples after filtration in your lab notebook. Did any of the water samples change color? Do you observe a difference depending on dye concentration or type of activated carbon?
9. Assess the color of all the filtered water samples. Carefully remove the coffee filters to have a better look inside the cup. Assign each of the water samples a color number based on the color scale described in step 4. Write down your results in your data table.
10. If you have a camera available, **take a photo of all the solutions that you collected in the filtration cups after the filtration experiment. Again, this will be helpful for your display board.** Make sure that all the pictures are taken with the same lighting, background, and camera settings that you used in step 6 (it is probably best to use a white background) so you can compare them to each other.
11. Once you have filled out your data for trial 1, set up and perform two more filtration trials starting with "Preparing Your Samples and Filters". Responsible scientists always do their experiments at least three times to confirm that their results are always showing the same trend, meaning that they are reproducible.

Analyzing Your Data {Please note that the information provided below is not exclusive to the data analysis section/discussion section. Please see course website lab report tab for more details.}

1. Calculate the average color rating for each of your water samples after treatment. To do this, for each of your samples add the color values from each individual trial and then divide the result by 3. Write down the average into your data table.
2. Compare the average color values that you wrote down for each experimental condition before and after the filtration. Can you see a trend in your data? Did your water samples become less colored or even colorless after filtration? Did the filtration material or the dye concentration make a difference?
3. More *advanced students* can do more quantitative measurements of the water colors, using a color picker tool online. Looking at each of your filtered water samples, select the corresponding color from the color palette for each one. You can use the left-over dye solutions that you prepared in the beginning as reference for the "before treatment" samples. The tool gives you color values for H (Hue), S (Saturation), B (Brightness) and R (Red), G (Green) and B (Blue). Stay within the same Hue for your color assessment (keeping the arrow on the right bar fixed at one setting) and for each selected color write down the color saturation (S) and brightness (B) value. Calculate the average of your determined brightness and saturation values from the three trials for all your experiments. *Note*: With lighter colors of your water samples, you should see an increasing value for brightness.
4. For each type of carbon (granular carbon, powdered carbon and no activated carbon) make a bar graph comparing the observed color (either using the average color numbers or for more advanced students the average brightness values) before and after filtration. On the x-axis put the dye concentration (0, 2 and 5 drops/cup of liquid) and on the y-axis graph the average color number (or if you chose the color picker tool, the average color brightness values) before and after the filtration process. You can either make a separate graph for each dye concentration or use one bar graph with different colors indicating the different dye concentrations. The Bibliography lists an online graphing tool that can help you create graphs.
5. If you chose to use the color picking tool, make another graph similar to that in step 4, but this time plot your average saturation values on the y-axis.
6. When using the color picker tool, remember that the higher your brightness values are, the clearer your water is. A higher saturation value means that the water is more colored. A combined saturation value of 0 with a brightness value of 100 means that your water is clear and has no color anymore!
7. Comparing all your graphs, can you tell if granular or powdered carbon is the more efficient filter using a contact time of 10 minutes? How do you think you can improve the efficiency of your filters?

Repeat the entire lab exercise using one of the recommended variations provided later in the lab packet. For example, using gauze instead of coffee filter paper. No two groups should be using the same variation for this part of the lab exercise. Please confer with other groups to make sure that you are not doing the same variation of the lab exercise.

Variations

- **Using more, or less, activated carbon**
  - In this project you used the same amount of activated carbon for each experimental condition. Do you think the results will change when you use more, or less activated carbon? Repeat this experiment but this time vary the amount of activated carbon you put into your filters. You can either choose another amount of activated carbon for the different dye concentrations or keep the dye concentration constant and vary the amount of activated carbon instead.
- **Contact Time**
  - You may want to find out how water cleanup is dependent on the contact time. Design an experiment in which you investigate the dependence of contact time on the filtration efficiency. Do a time series with different contact times for your water samples and activated carbon. You can also change the dye concentration in your water sample for these experiments if necessary.
- **Reusing of Activated Carbon**
  - Can the activated carbon you used for your experiment be re-used for another water sample? After how many filtration steps did you reach the adsorption capacity of the carbon? Does it depend on the dye concentration of your water sample? Design an experiment to find out!
- **Separation of Other Mixtures**
  - What else can be filtered with activated carbon? Do other food colors give you the same results? Try separating other mixtures with your carbon filter such as a **sand/soil and water mixture, or a mixture of oil and water.**
  - What about **removing smells** from your water sample, do you think you can filter out a vanilla or peppermint aroma?
- Impacts of Temperature/pH
  - Besides contact time and particle size, what other parameters can influence the filtration efficiency of your water filter? Do you think the temperature of the water sample makes a difference? What about the pH of your water sample? Test your hypotheses by varying these parameters and see how clean your water gets each time!
- If you are interested in the environmental aspect of water filtration or using more different filtration materials, check out the Science Buddies science project From Contaminated to Clean: How Filtering Can Clean Water.

Bibliography for Introduction

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