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LESSON:

Cleaner Air and Water on the Fly

Summary: Students conduct an experiment using activated charcoal to purify water "contaminated" with blue food dye. Then, they read an article about activated charcoal and unburned carbon as a method for removing mercury from flue gases being emitted by coal-fired power plants.

Lesson Type: Experiment—Students collect, manipulate, and/or summarize data from an experiment or activity they conduct.

***EHP* Article:** "Cleaner Air on the Fly?"
EHP Student Edition, August 2006, p. A277
http://www.ehponline.org/docs/2006/114-5/forum.html#clea

Objectives: By the end of this lesson, students should be able to:

1. explain the process of chemical adsorption;
2. describe how adsorption is used to help purify air and water; and
3. design and implement an experiment to test how different variables (such as particle size or amount of activated carbon) impact the adsorption efficiency of activated carbon (if doing inquiry version of the lesson).

Class Time: 45 minutes, 2 hours if students conduct the inquiry experiment

Grade Level: 9–12

Subjects Addressed: Environmental Sciences, Chemistry, General Science

Prepping the Lesson (15 minutes)

INSTRUCTIONS:

1. Download the entire August 2006 *EHP Student Edition* at http://www.ehponline.org/science-ed/, or download just the article "Cleaner Air on the Fly?" at http://www.ehponline.org/docs/2006/114-5/forum.html#clea.
2. Review the Background Information, Instructions, and Student Instructions.
3. Read the article "Cleaner Air on the Fly?"
4. Assemble the materials needed for the laboratory activity.
5. Make copies of the article and Student Instructions, as necessary.
6. Decide whether you will have the students design and perform an inquiry experiment as part of the lesson. If so, this should follow Step 6 of the lesson. After completing the inquiry, students can go onto Step 7. Ideas for inquiry experiments are in the "Notes & Helpful Hints" section.

MATERIALS

Per Student

- 1 copy of *EHP Student Edition*, August 2006, or 1 copy of the article "Cleaner Air on the Fly?"
- 1 copy of the Student Instructions

Per Group

- Activated charcoal (25 g or 1 oz)
- Blue food dye
- Cotton balls
- Eyedropper
- 100-mL beaker or clear plastic cup (7 oz)
- 500-mL beaker or equivalent
- Mortar and pestle (100 mL or larger)

- 50-mL graduated cylinder
- Sheet of paper
- Ruler
- Stirring rod or equivalent to push the cotton into the turkey baster
- Turkey baster without the suction bulb (1 oz) or equivalent

VOCABULARY:
- absorption
- activated charcoal
- adsorbant
- adsorbate
- adsorption
- chemisorption
- flue gas

BACKGROUND INFORMATION:
Adsorption is a process commonly used to remove pollutants from contaminated air and water. The surface of a solid or liquid attracts and retains gases or dissolved contaminants with which they come in contact. The contaminant that is adsorbed is called the adsorbate, and the solid or liquid surface that does the adsorbing is called the adsorbant. The forces binding the adsorbate to the adsorbant may be physical and/or chemical. Physical adsorption involves intermolecular forces of attraction between the adsorbate and the adsorbant. Chemical adsorption (chemisorption) involves a chemical reaction and bonding between the adsorbate and the adsorbant. Adsorption efficiency decreases over time, and adsorbants need to be replaced or reactivated. Adsorption should be distinguished from absorption, in that absorption involves not only retention of contaminants onto the surface of a solid or liquid but also passage of the contaminants into the interior of the solid or liquid.

Activated carbon or charcoal is a solid that is often used as an adsorbant. It is treated (activated) to increase its porosity and surface area, making it very suitable for removing contaminants by adsorption. It is most effective against nonpolar organic contaminants. Other materials such as activated alumina, silica gel, molecular sieves, and zeolites are also used because of their porosity and high surface area.

RESOURCES:
Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov. Choose Air Pollution, Energy

International Adsorption Society, What is adsorption?, http://ias.vub.ac.be/What%20is%20adsorption.html

Kvech S, Tull E. *Water Treatment Primer: Activated Carbon*, http://ewr.cee.vt.edu/environmental/teach/wtprimer/carbon/sketcarb.html. Includes close-up pictures of activated carbon.

U.S. Environmental Protection Agency, http://www.epa.gov

Mercury, http://www.epa.gov/mercury/index.htm

Controlling power plant emissions: overview, http://www.epa.gov/mercury/control_emissions/index.htm

Human health, http://www.epa.gov/mercury/health.htm

Wikipedia Online Encyclopedia, Adsorption, http://en.wikipedia.org/wiki/Adsorption

Implementing the Lesson

INSTRUCTIONS:
1. Tell the students they are going to investigate the use of activated charcoal to purify water.
2. Divide the students into groups and pass out the materials, Student Instructions, and a copy of the article "Cleaner Air on the Fly?" Have students complete the activity.
3. Discuss with students the answers to their questions, the health effects of mercury, and why it is important to remove mercury from the environment.

NOTES & HELPFUL HINTS:
- The size of the activated charcoal is important for making the experiment work. The charcoal should be the size of coarse sand. If charcoal size is too large, the colored water will simply flow around the charcoal (called channeling) without coming in contact with the surface of the charcoal. In this situation, the water will not be purified and some colored water may pass through the charcoal bed. The colored water is added slowly at the beginning using an eyedropper to help prevent channeling. If the charcoal particle size is too small, the water will not be able to pass through the charcoal.

- Activated charcoal/carbon can be purchased from a chemical supply company. Purchase 50-200 MESH charcoal. Activated charcoal of this size range may not need to be ground up by the mortal and pestle. Activated charcoal may also be purchased at pet supply stores because it is used to purify water in aquariums. However, aquarium activated charcoal is too large to use as is and will need to be ground with by the mortal and pestle.
- If you do not have mortars and pestles, students can place the activate charcoal in a plastic bag and crush it with a hammer, being careful not to damage the underlying surface. The charcoal can be separated by size using screens with different mesh sizes. These different sizes of charcoal could be used as a variable for an inquiry experiment.
- Food dye of any color may be used.
- Any apparatus that has a cylindrical tube that is 0.5" to 1" in diameter and that can be blocked at one end to keep the charcoal in the tube may be substituted for the turkey baster. A 1" × 6" gravel vacuum found at pet supply stores is an example of an alternative.
- Providing students with opportunities for designing and conducting an inquiry-driven experiment is recommended and will advance their science skills. After students complete Step 6, have them identify the variables that may affect the collection efficiency of the charcoal. Then, have them design an experiment with a hypothesis to test one of the variables. Finally, if the time and resources are available, have them conduct their experiment. The following are variables that they might want to manipulate:
  - vary the particle size of the activated charcoal
  - vary the height of the charcoal in the turkey baster (e.g., 1", 2", and 3")
  - vary the amount of food coloring (e.g., 1 drop, 2 drops, and 3 drops)
  - determine the volume of food-colored water the activated charcoal can filter before the colored water begins to come out the bottom (i.e., find the saturation or breakthrough point)
  - vary the flow rate
  - see if chlorinated water, distilled water, and salt water impact the ability for the activated carbon to remove the color
- One of the challenges in conducting an inquiry experiment is to keep all the variables constant except for the one variable you are trying to test. In the lesson, the flow rate of the food-colored water through the charcoal is controlled by gravity. If you continue to use gravity to draw the water through the charcoal, changing the particle size, the height of the charcoal, the volume of food-colored water being added, and how you add the water to the charcoal will also change the flow rate. To accurately measure the impact of the variables, you need a way to keep the flow rate constant. Connecting the end of the turkey baster to a vacuum system through a water trap, while trying to keep the vacuum system pressure constant, might be one strategy. A vacuum bleed might be one way to control the pressure drop.
- The experiment could also be done as a demonstration.

Aligning with Standards

SKILLS USED OR DEVELOPED:

- Communication (notetaking—oral, written)
- Comprehension (listening, reading)
- Critical thinking and response
- Experimentation (conducting, data analysis, design)
- Manipulation
- Observation
- Technological design

SPECIFIC CONTENT ADDRESSED:

- Adsorption
- Air and water purification
- Environmental health

NATIONAL SCIENCE EDUCATION CONTENT STANDARDS MET:

Unifying Concepts and Processes Standard

- Systems, order, and organization
- Evidence, models, and explanation
- Constance, change, and measurement
- Form and function

Science as Inquiry Standard
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science Standard
- Structure of atoms
- Structure and properties of matter
- Chemical reactions

Science and Technology Standard
- Abilities of technological design
- Understandings about science and technology

Science in Personal and Social Perspectives Standard
- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

History and Nature of Science Standard
- Nature of scientific knowledge

Assessing the Lesson

Step 6: Observe the water dripping out of the turkey baster at the bottom.

a) Describe what you see.

The water dripping out the bottom of the turkey baster, after passing through the charcoal, is clear or much less blue in color.

b) Provide an explanation for what you observed.

The charcoal adsorbed the blue color onto the surface of the charcoal, removing it from the water. Activated charcoal is specially treated to make the charcoal highly porous and increase its surface area. The more surface area, the more effective it is in removing contaminants.

Step 7: Read the article "Cleaner Air on the Fly?" and answer the following questions:

a) How does activated charcoal injected into the flue gas remove mercury?

The activated charcoal injected into the flue gas removes the mercury by the process of adsorption using the same mechanism observed with removal of the blue food dye from the water.

b) How does unburned carbon in the fly ash capture mercury?

It is not clear how the unburned carbon removes mercury from the flue gases, but it could be by adsorption.

c) What is the connection between what you observed using activated charcoal and blue water, and mercury being removed from emissions from coal-fired power plants?

The injected activated charcoal in the flue gases may remove the mercury the same way the activated charcoal removed the blue color from the water; that is, by adsorption.

d) What are some common uses of activated charcoal around the home?

Activated charcoal is widely used in many products primarily for the purpose of adsorbing and removing contaminants from air and liquids. Some stand-alone indoor air cleaners contain activated charcoal filters to remove contaminants from air. Some tap water filters also contain activated charcoal to remove contaminants from water. Aquariums also used activated charcoal to remove contaminants in the water. In some cases, activated charcoal tablets are prescribed by doctors in the treatment of poison victims to adsorb the swallowed contaminants and prevent the poison from getting into the body.

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Give us your feedback! Send comments about this lesson to ehpscienceed@niehs.nih.gov.

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STUDENT INSTRUCTIONS: Cleaner Air and Water on the Fly

Step 1: Carry out the following experiment and record your observations and conclusions.

Materials:

- Activated charcoal
- Blue food dye
- Cotton balls
- Eyedropper
- 100-mL beaker or clear plastic cup (7 oz)
- 500-mL beaker or equivalent
- Mortar and pestle (100 mL or larger)
- 50-mL graduated cylinder
- Sheet of paper
- Ruler
- Stirring rod or equivalent
- Turkey baster without the suction bulb (1 oz) or equivalent

Step 2: Take a small piece of cotton and push the cotton into the turkey baster with the stirring rod so that the cotton is blocking the small opening at one end. Stand the turkey baster nozzle side down in the 500-mL beaker.

Step 3: Fill the mortar and pestle about half full with activated charcoal. Grind the charcoal until it is the size of coarse sand. Pour the charcoal into the turkey baster to a height of about 4". You may use a sheet of paper twisted like a funnel to help transfer the charcoal into the turkey baster (Figure 1).

Step 4: Measure 50 mL of water into the graduated cylinder and pour the water into the 100-mL beaker. Add one drop of blue food dye to the water and stir gently by swirling the beaker.

Step 5: With the turkey baster still standing vertically inside the 500-mL beaker with the nozzle end pointing down, use the eyedropper to slowly add drops of the blue water to the center of the charcoal at the top of the turkey baster. After about 50 drops, you can add the water more rapidly. Once all the charcoal is thoroughly wet, you can pour more blue water into the top of the turkey baster, space permitting.

Step 6: Observe the water dripping out of the turkey baster at the bottom.

a) Describe what you see.

b) Provide an explanation for what you observed.

Step 7: Read the article "Cleaner Air on the Fly?" and answer the following questions:

a) How does activated charcoal injected into the flue gas remove mercury?

b) How does unburned carbon in the fly ash capture mercury?

c) What is the connection between what you observed using activated charcoal and blue water, and mercury being removed from emissions from coal-fired power plants?

d) What are some common uses of charcoal around the home?