Nanofiltration

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Abstract

Contaminated water supplies have become local problems in communities across the United States and world. Though dramatic situations in Flint, Michigan, and in New Orleans after Hurricane Katrina catch the headlines, neighborhoods and communities across our country are facing water quality issues in their groundwater, swimming pools, and community and backcountry lakes and streams. Microscale and nanoscale water filters hold the key to removing even the smallest of pathogens from the water. In this module, students will use a model to illustrate the relationships and interactions between clean water, micro- and nano-contaminants found in local water sources, and mechanical water treatment mechanisms. Then they will evaluate competing design solutions to produce drinkable water based on empirical evidence and/or logical arguments regarding constraints, including cost and safety, while considering social and environmental impacts.

Outcomes

After completing this module, students will be able to

- distinguish among different sizes of objects at the micro- and nanoscale and how they influence the design of technology.
- understand how to compare different models by identifying the benefits, risks, and limitations of each.

Prerequisites

Basic understanding of

- biological cells
- water quality and what degrades it
- size and scale of object that may be found in water

Science Concepts

- Living things are made of one or more cells.
- Natural resources guide the development of human society.
- The sustainability of human society is dependent upon responsible management of natural resources.
- Macroscopic models help us investigate and understand how a design would work at smaller scales,i.e., the micro- and nanoscales.

Nanoscience Concepts

- Nature/structure of matter - Atomic and molecular structure.
- Sense of Scale.
- Societal Impacts.

Background Information

Water in Context

You have likely already done things today with water that many people in the world cannot do – like take a shower, drink water from the tap, and flush the toilet. Unlike the rest of the world, where a lack of water is linked to poverty and is one of the leading causes of death due to waterborne disease, the U.S. enjoys considerable water affluence. As a general rule, our water quality concerns are limited to episodic outbreaks of waterborne disease caused by pathogens in untreated water. For example, the Centers for Disease Control reports that in 2009-2010 there were 33 drinking water–associated outbreaks that resulted in 1,040 cases of illness, 85 hospitalizations, and nine deaths.

Episodic outbreaks of waterborne disease in the U.S. occur during natural disasters, such as Hurricane Katrina in 2005 or tropical storm Sandy in 2012, or when the local infrastructure is contaminated or fails to work such as the 1993 *Cryptosporidium* outbreak in Milwaukee, WI which lead to 400,000 illnesses and up to 100 deaths. When these events occur, the public may be told to boil their water as a way to treat it to prevent waterborne pathogens. And this works for most harmful disease-causing microorganisms, like bacteria, but not all of them, like cryptosporidium.

The population of the U.S. continues to rise, gaining 2 million people from 2012 to 2013. So, the demand for clean water will also rise. This will become more of a problem as we are using ground water from the available aquifers faster than they are refilling. So how do we use technology to ensure our ability to continue to use sanitized water for many of the things that many people in the U.S. take for granted (like showering, drinking water from the tap, and flushing the toilet) and not doing as many people in many countries do by using untreated water for these functions?

Typical Water Treatment

Typical water treatment in the U.S. involves a number of steps to remove undesirable objects like sticks, tastes like algae, waterborne pathogens like as hepatitis A, and chemicals like lead. The Environmental Protection Agency (EPA) lists these as typical steps for treatment:

1. Coagulation – addition of chemicals to attract dirt in preparation for sedimentation.
2. Sedimentation – coagulated dirt particles are allowed to settle out of the water.
3. Filtration – mechanical filters are used to remove small particles.
4. Disinfection – chlorine compounds are typically added to the water to kill bacteria and microorganisms.

Chlorine has been a lifesaver when it comes to sanitizing drinking water. It kills many harmful pathogens and maintains the taste and cleanliness of the water while it is stored between processing and use. It also has some disadvantages such as its affinity to combine with organic materials to produce trihalomethanes and haleoacetic acids – which are long-term exposure carcinogens. Is the benefit of using chlorine worth the risk of potential exposure?

Presence of Waterborne Pathogens

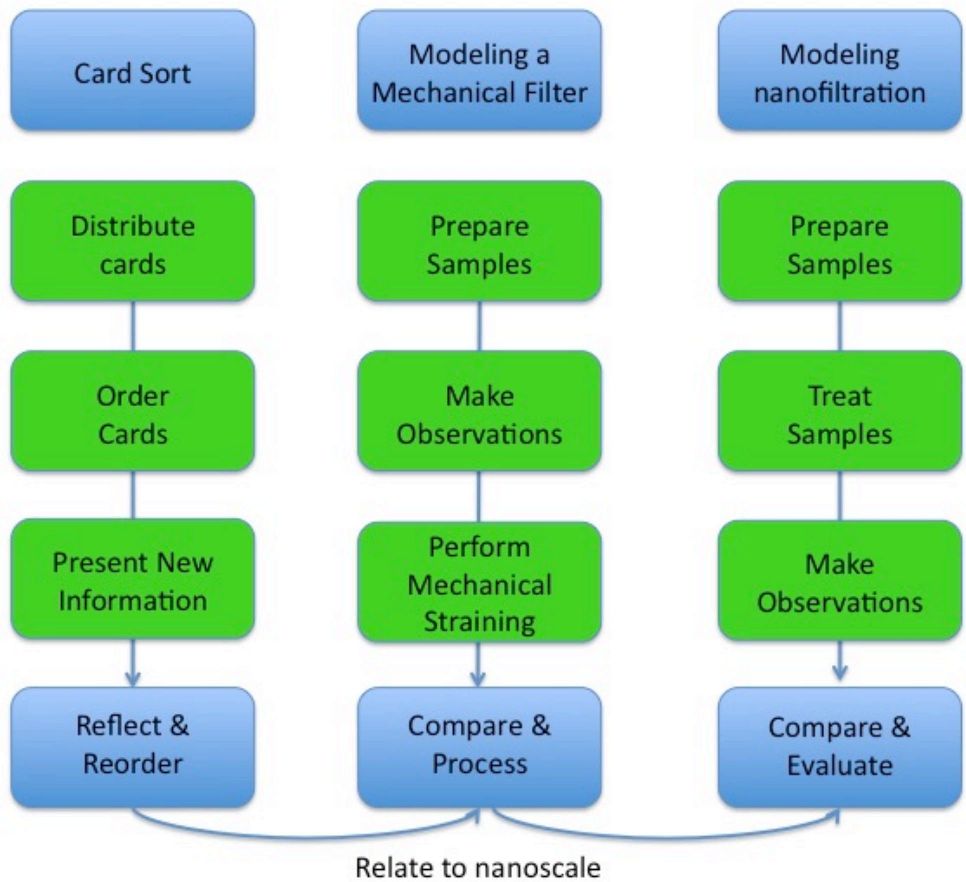
Waterborne disease is caused by pathogens found in the fecal matter in the water supply. This means that water drawn from surface sources, such as rivers and lakes, is frequently contaminated. While it takes 10–1,000 bacteria to make you sick, it only takes one virus. Some viruses, such as hepatitis A or rotavirus, are hard to detect using conventional methods. Other diseases, such as *Cryptosporidium*, resist chemical treatment and are removed only by filtration. The size of these pathogens becomes critically important in designing a way to filter them out of drinking water.

Current and Future Applications

Nanofiltration is most commonly used to purify drinking water by removing nanoscale pollutants like heavy metals, pesticides, and nitrates. It can soften water by removing scale-forming ions, decolor wastewater to make it clear, and help in the process of water desalination. New applications of the nanofilter are in production of milk, juice production, pharmaceuticals, and fragrances. It is being used in the petroleum industry to remove toxins in oil sands water, and in the medical field to extract amino acids and lipids from blood and cells.

Learning Activity: Nanofiltration

Activity Flow Chart



Activity Materials

For each group of three to four students, you will need:

Activity 1
- 1 set of waterborne pathogens cards
- Data table on water pathogens

Activity 2
- Materials to construct a filter such as cheesecloth, activated carbon, grass, dirt, pillow batting, coffee filter, etc.
- Plastic funnel
- Ring stand
- Samples of items that are typically washed down the sink such as toothpaste, coffee grounds, dirt from vegetables, shampoo, soda, etc.
- 3 beakers
- Stir rods (wood or glass)

Activity 3
- Light microscope
- Wet-mount slides & cover slips
- Eyedropper
- Untreated water from local lake, pond, or stream
- Tap water
- Optional: 1 Coliform Bacteria Test Kit

For each class, you will need:
- 1 Lifestraw
- 0.5 m of rubber tubing
- 1 – 35cc syringe

Hazard Warning: Do not drink the untreated or "raw" water. Wash your hands thoroughly after working with this water.

Length of lesson: **50 minutes**

Activity

Part 1 Card Sort

It's easy to lose perspective about how small things are when you cannot touch them. You cannot touch things in the nanoscale world that consists of materials that are between 1 and 100 nm in size. We cannot study the nanoworld with light because the wavelengths of light (400-700 nm) are too big to be a useful tool to detect the nanoscale world. Scientific understanding of this world has been greatly enhanced by advances in technology, such as the invention of the atomic force microscope (AFM) in the early 1980s. Sorting materials from largest to smallest can help you maintain a sense of scale as you think about the nanoscale world that is too small for you to directly see.

These cards contain images of some common sources of waterborne contaminants. How small are they? Can you see them under a microscope? This activity is to help you gain some landmarks in this tiny world.

1. Order the common water pathogen cards in terms of width – from widest to narrowest. Record your order.

2. Why did you organize them this way? What clues did you use?

3. After looking at the PowerPoint slide or paper copies of the data table on water pathogens, make any changes to your card organization from widest to narrowest. Record the new order. Why did you make the changes?

Note: Keep these reference points in mind as you complete Activities 2 and 3.

Part 2: Modeling a Mechanical Filter

Models are used by scientists to help them represent the system being modeled, to help them better understand what is happening with the system, to make predictions, and to generate questions about the system being studied. They are very useful when trying to study objects that are too small to be studied directly, like nanoscale objects.

This activity uses cheesecloth to model the process that nanomechanical filters use when processing water.

1. Prepare "dirty" water by combining items you commonly send down the drain and mixing them in Beaker 1.
2. Pour some (but not all) of the water through the following:
    a. Strain with one material from those provided (beaker 2)
    b. Strain with multiple materials from those provided (beaker 3)
3. Write and draw your observations of this water.

Optional: Reserve the fluid in beaker 3 for use and testing using the mechanical filter (Activity 3).

Hazard Warning: Don't drink this water, or any water from an uncertain source!

4. Why is this water still not "safe" to drink? What evidence (color, consistency, clarity) would support this assumption? How would this evidence affect the steps for cleaning water in a water treatment facility?
5. If the materials, like coffee grounds or toothpaste, represented harmful bacteria, describe how effective your filter would be at cleaning the water.
6. Describe a cleaning system that would be able to remove all contaminants.

Part 3: Using a Mechanical Filter to Model Nanofiltration

Nanofiltration is a membrane filtration process that can be used with water that doesn't have a lot of debris. The "holes" or pores that the water passes through are about 10 nm). One advantage of this kind of filter is that membranes can be used to mechanically filter out pathogens without requiring chemical treatment. This avoids the possibility of long-term exposure to chlorine or the carcinogens it forms when it reacts with organic solutes in the water.

This activity employs a mechanical microfilter (not a nanofilter) to clean the water and models the process of nanofiltration.

1. Prepare a wet mount slide of a sample of each type of water.
2. Look for microorganisms using the microscope and record your results.

Hazard Warning: Do not let the water from this activity sit for prolonged durations because it could contain pathogens.

3. Test the LifesStraw microfilter, or other microfilter your instructor provides. (You will have to share with your classmates.)
    a) The splicer is attached to the LifeStraw by a rubber hose. Connect the splicer to the Syringe.
    b) Place the LifeStraw into the water and pull the syringe plunger up halfway.
    c) Remove the LifeStraw from the water.
    d) Invert the LifeStraw and finish pulling the plunger on the syringe the rest of the way, being careful not to pull it out of the syringe.

4. Look for microorganisms using the microscope and record your results.
5. Select one sample to test the "treated" water for presence of coliform bacteria. Follow the directions from your coliform test. *Note*: Results take 24–48 hours.
    - Why did you select that sample to test for coliform bacteria?
    - What were your results?

6. Why did we test for coliform bacteria?
7. What kinds of contaminants might be missed by only observing the water under the microscope?
8. How would you test for the contaminants you could not see with the microscope?

Discussion Questions

1. The modeling process
    a. Evaluate the different model filters you worked with (i.e., cheesecloth, LifeStraw).
        i. What were the models' strengths?

        ii. What were their limitations?

    b. How would you design a new filter to improve its ability to remove all contaminants?

2. Evaluate water treatment methods
    a. Which filtration method would you personally choose for water treatment following a disaster in your community, like a severe flood or prolonged power outage? Why?

    b. What constraints, such as cost, safety, societal or environmental impacts, would determine your choice?

c. What are the benefits and risks of your personal choice?

d. Which water treatment methods would you recommend for your city/community?

e. What constraints, such as cost, safety, societal or environmental impacts, would determine your choice?

f. What are the benefits and risks of your choice for your city/community?

Contributors

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Multimedia Resources

Videos and Images

- Infographic: The Water Rich Versus The Water Poor seametrics.com/blog/water-rich-poor-infographicHow Lifesaver works: youtube.com/watch?v=RMzHS9yoc5I
- Lifesaver story: youtube.com/watch?v=ffW7b8F6ue8&feature=youtube
- Lifesaver TED talk: ted.com/talks/michael_pritchard_invents_a_water_filter.html

Articles

- Lifesaver Systems iconlifesaver.com
- Another Tiny Miracle: Graphene oxide soaks up radioactive waste news.rice.edu/2013/01/08/another-tiny-miracle-graphene-oxide-soaks-up-radioactive-waste-2
- Students find high bacteria levels in Hamilton creek. cbc.ca/news/canada/hamilton/news/students-find-high-bacteria-levels-in-hamilton-creeks-1.1131759

- A teabag style filter for Africa: phys.org/news201320077.html
- Nanofiber Filters Eliminate Contaminants: nasa.gov/pdf/41308main Nanofiber.pdf