Deinking Recycled Paper through Flotation

- TEACHER GUIDE -
Deinking Recycled Paper through Flotation

OVERVIEW

- Recycling paper is a highly important process worldwide. Effective and efficient recycling of wastepaper is crucial to produce high-quality products while minimizing the use of resources (e.g., water, electricity).
- This activity will help students understand the many challenges around recycling, as well as various chemical and physical factors that impact the process and efficiency of de-inking recycled paper using a flotation technique.
- This hands-on, student-centered activity is inexpensive, simple, and safe and will allow groups of students to investigate the purpose of flotation in the de-inking process, test different variables to determine their effects on the de-inking process, and qualitatively and quantitatively analyze and interpret their results in terms of contaminant removal efficiency.

OBJECTIVES

Students will:

- Analyze the global challenges around recycling in general and the unique challenges associated with recycling paper (collection, contaminant removal, yield).
- Understand the relationship to human behavior (i.e. reducing the use of plastics, renewable packaging, etc.) and the ways that constraints impact the feasibility of society's wants and needs (i.e. we want to use recycled paper, but at the same time we want to reduce our paper consumption, so this leads to a lower supply of raw materials available to make recycled paper) (ETS1-1)
- Explain how the recycling of paper impacts the availability of natural resources (e.g., trees, but also in terms of energy and water) (ESS3-1)
- Explain the chemical basis and process (i.e. molecular structure, forces, energy) of de-inking recycled paper using the flotation technique (PS1, PS2, ESS3-4)
- Quantify paper cleanliness by calculating contaminant removal efficiency.
- Refine the operation of flotation equipment to improve the contamination removal efficiency (ESS3-4, ETS1-1)
- Evaluate these competing design solutions on a cost-benefit ratio (i.e. cost of foaming agent based on the concentration used vs. the impacts of recovering more/less fibers vs. removing more contaminants) (ESS3-2)

CONTENT STANDARDS

This lesson is appropriate for high school physical science/chemistry and environmental science courses and addresses the following Next Generation Science Standards:

Performance Expectations

- HS-ESS3 (Earth and Human Activity, mainly parts 1, 2, 3, and 4)
- HS-ETS1 (Engineering Design, mainly part 1)
- HS-PS1 (Matter and its Interactions)
- HS-PS2 (Motion and Stability: Forces and Interactions)

Science and Engineering Practices

- Asking questions and defining problems
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations and designing solutions
- Obtaining, evaluating, and communicating information

Crosscutting Concepts

- Energy and matter
- Structure and function
- Patterns

MATERIALS

- Common household blender
- Handsheet mold
- Shallow tray (3-4 inches depth)
- Plastic tub/storage container (8-12 inches depth)
- Air diffuser
- Foaming agent
- Tap water
- Assortment of paper with moderate printing (e.g., newspaper, printed copy paper, magazine paper)
- Ruler

SAFETY

- Blenders are the primary hazard in this lab activity and must be used properly. Only place appropriate reagents and materials inside the blenders. Students should never place fingers or hands in a blender that is installed on its motor. Always blend with the blender cover on.
- This activity uses common household materials and does not involve chemical hazards.
- Teachers should always require that students understand and adhere to safe laboratory practices when performing any activity in the classroom or lab. Demonstrate the protocol for correctly using instruments and materials, and model proper laboratory safety practices for your students. Use personal protective equipment such as safety glasses or goggles, gloves, and aprons when appropriate.

BACKGROUND INFORMATION

This activity fits in and applies to several different topics, including surface and separation science and engineering design. It is particularly useful in exemplifying separation based on hydrophobicity/hydrophilicity.

The deinking of wastepaper includes several operations. These include pulping, screening, centrifugal cleaning, washing, flotation, bleaching and kneading. In the flotation process, air bubbles are passed through a low consistency pulp stock. A foaming agent is added to create foam on the surface of the pulp stock. Hydrophobic particles (hopefully contaminants such as inks) attach to the bubbles and are lifted preferentially away from the pulp stock, rising to the top of the container and residing in the foam. The foam is scraped away as a “reject” stream, producing cleaner fibers in an “accept” stream that are used to create the desired recycled paper product. Unlike this laboratory exercise, the industrial flotation process is continuous, having constant feed, accepts and rejects flow.

The deinking through flotation separation process is not 100% efficient, and its efficiency can be calculated by using a feed sample (pulped but no flotation) as comparison. It is also important to understand the tradeoff between fiber yield and cleanliness efficiency. Generally, rejecting a large amount of feed material (low fiber yield) will produce a very clean sample, while rejecting a small amount (high fiber yield) will decrease contaminant removal efficiency. Industrial flotation processes must achieve a balance between these two outcomes in order to produce their desired product and meet their manufacturing needs.

TIME REQUIREMENTS

- Prep time: 15 minutes
- Class time: 1 to 2 class periods, depending on design of student-driven investigations and handsheet drying method

PREPARATION

1. Ensure each group of students has the necessary supplies
2. See Figures 1 and 2 for suggested setup.

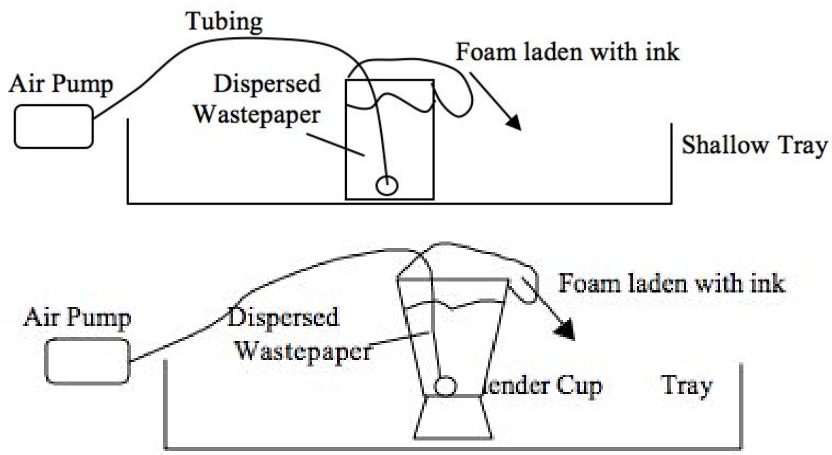

Figure 1. Flotation deinking set-up.

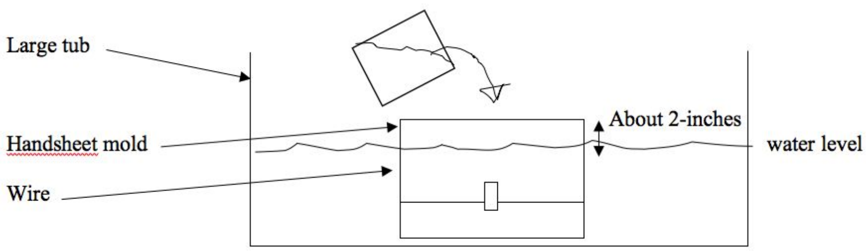

Figure 2. Schematic of the handsheet mold.

PROCEDURE

1. Put 1000 mL of hot/warm tap water in the blender cup.
2. Tear about 4.5 grams of air dry copy paper (typically one sheet) with moderate printing and place in the blender. *The size of the torn paper does not matter as long as the paper will fit into the blender*
3. Cover the blender and blend for 45 seconds.
4. Put the blender cup ONLY (NOT the blender motor) in the shallow tray. *Be careful when removing the blender cup from the motor, depending on the model, the cup will simply lift off. If you try to twist off the cup, you will remove the base and the sample will spill out.*
5. Add 5 drops of foaming agent to the blender cup and stir. Use the ruler to make sure the fibers and the foaming agent are well dispersed. *Some of the ink particles may adhere to the side of the blender in a "ring." If this happens, use the ruler to scrape the ink off the side of the blender before proceeding.*
6. Carefully fill the blender cup with cold tap water to fill the blender cup (liquid should be almost overflowing from the cup). *Keeping the water level high makes it easier to scrape off the rejects.*
7. Connect the air diffuser with the tubing and the air pump and turn on the pump. *You should make sure that the fiber has not risen to the top before turning on the pump. If the fiber has risen to the top, vigorously mix the contents of the blender cup so that the fiber is dispersed throughout the container.*
8. Place the air diffuser into the bottom of the blender cup for 3 minutes. Manually scrape foam off the top into the shallow tray. You may add water to the blender to keep the liquid surface near the top.
9. Remove the bubbler from the blender cup. The material remaining in the blender is the "ACCEPTS" sample. The material scraped into the shallow tray is the "REJECTS" sample. Qualitatively note the characteristics of the REJECTS and then discard.
10. Make a handsheet out of the ACCEPTS sample. Make sure to clean the mold after use.

MAKING A HANDSHEET:

1. Use the handsheet mold submerged in water in a plastic tub. Water level should be 2 inches below the top of the handsheet mold
2. Add ACCEPTS pulp to the handsheet mold, lift carefully and allow to drain, place mold on flat surface, remove top of mold.
3. Place 2 blotters on the wet pad, press with hand in UP AND DOWN MOTION ONLY (not side to side), remove top blotter but do not remove the blotter touching the pad.
4. Replace top blotter with a single dry one and press again. Repeat the replacement of top blotter until very little water is removed. *It will take 4-6 blotters in total. (NOTE: If the teachers are short on time, they can have the students place 5 blotter papers on at the beginning instead placing and pressing them one-by-one.)*
5. Peel blotter in contact with the sheet off mold wire together. place another blotter on top of the handsheet and take your handsheet to the dryer. *The handsheet should not come into contact with the dryer. Make sure to write your name on one of the blotter papers.*

CALCULATIONS

The following will provide a quantitative evaluation of your de-inking results:

Calculate the yield:

1. Weigh the paper used to start the experiment and the final paper product.
2. Yield = mass of the final paper product / mass of the input paper, as a percent.

Calculate the contaminant removal efficiency:

1. Mark off a 1 cm by 1 cm square (approximately) on the surface of both the ACCEPTS and FEED handsheets. Count the number of ink spots in the 1 cm^2 area. Record the results.
2. Repeat step 1 twice for both samples, recording data each time. Calculate the average number of spots/cm^2 for both samples.
3. Alternatively, use a scanner based image analysis system for dirt counting if available.
4. Calculate the contaminant removal efficiency of the flotation process as:
   %EFF = 100%*(FEED-ACCEPTS)/FEED, in which the values are # spots/cm^2.

EXAMPLE 5E OUTLINE

Engage (Expected time: 10 minutes)

1. “Setting the stage for the deinking lab activity" intro video: https://youtu.be/m56si-2ph2Q
2. Flotation cell video clip: https://www.youtube.com/watch?v=X7v9JYWH75E
3. Questions to spark student interest and curiosity (e.g., How many times could you circle the earth with all of the trash produced each year?) What real-world question/problem can we investigate?

Explore (Expected time: 20 minutes)

1. Students can follow the general procedure to make one ACCEPTS handsheet. FEED and REJECTS can be pre-made as comparison examples.
2. Float between groups to check on progress, ensure proper technique, ask probing questions, answer student questions.
3. Dry handsheets. Observe handsheet results.
4. Calculate contaminant removal efficiency and % yield

Explain (Expected time: 5 minutes)

1. Students share out their results and explain/discuss the core concepts behind the process.
2. Incorporate academic language and make sure students understand the underlying process (hydrophobicity, preferential separation, polar/non-polar)
3. Transition: How can we improve the ink-removal efficiency? How can you achieve the lowest PPM and retain the highest yield?
4. Groups discuss what variable they wish to test. Develop hypotheses.

Elaborate (Expected time: 20 minutes)

1. Students design a procedure improve ink-removal efficiency and yield.
2. Float between groups to check on progress, ensure proper technique, ask probing questions, answer student questions.
3. Dry handsheets. Observe handsheet results.
4. Calculate contaminant removal efficiency and % yield

Evaluate (Expected time: 5 minutes)

1. Discussion: What did you do differently this time? What happened differently? Why?

EXTENSION IDEAS

- Variables that students might be interested in testing:
  - Type of paper (newspaper, printed copy paper, magazine paper)
  - Type of ink (B&W vs. color)
  - Amount of foaming agent (e.g., 5 drops versus 12 drops)
  - Flotation conditions (water temperature, flotation/foam time)
  - Paper disintegration conditions (time, speed)
  - Series of multiple flotations
  - Proportion of paper (e.g., 50/50 copy paper and magazine; 25/75 copy paper and magazine)
- After making handsheets, students can test paper strength.

SUPPLEMENTAL RESOURCES

Published article in the Journal of Chemical Education	Venditti, R. A. (2004). A simple flotation de-inking experiment for the recycling of paper. *Journal of chemical education, 81*(5), 693.
Short video discussing overview of the paper recycling process	https://www.youtube.com/watch?v=jAqVxsEgWIM

ACTIVITY NOTES

- **Printed copy paper (B&W)**: this works best with single-spaced, double-sided printed paper, although, there will be noticeable differences between FEED and ACCEPTS using any amount of printing (double spaced, or single-side printing).
    - Using *cold water instead of warm/hot water* made a noticeable difference in the size of the ink spots on the ACCEPTS sheet. Cold water generated larger ink spots.
- **Magazine paper (B&W and color ink)**: doesn't foam/bubble very much with the standard 5 drops of foaming agent. The ink is very visible in the foam and cloudier than the B&W copy paper foam. The paper may clog the blender, so it helps to blend on high initially and then switch back to lower speed.
    - **Feeds**: handsheet has so much ink that the paper appears pink. Very difficult to count individual ink spots. This is an interesting learning moment, however, to discuss with students the complexity of cleaning paper that has color ink and the implications (e.g., having to bleach paper if ink is not efficiently removed).
    - **Accepts**: noticeably cleaner, appears to be white/grey. Ink spots are not well-resolved, however, so it is difficult to count individual ink spots.
- **Newspaper (B&W and color ink)**: Barely foams at all, even with extra foaming agent (12 drops). The paper may clog the blender, so it helps to blend on high initially and then switch back to lower speed.
    - Although this protocol is not optimized to de-ink newspaper, it is an interesting discussion-starter on why we see these differences between printed copy paper, magazine paper, and newspaper. The paper quality and original "dirtiness" of the paper makes a difference.

Student Handout
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QUESTIONS

1. What is the contaminant removal efficiency of the flotation process?
2. Can you think of ways to modify the flotation experiment to increase the contaminant removal efficiency? Briefly explain why you think the modification will improve contaminant removal efficiency and list any negative impacts the modification may have.
3. Some pulp fiber is scraped away with the rejects in the foam. Why is this undesirable in an industrial process and how does it impact the feasibility of meeting society's needs in terms of paper recycling?
4. Why is the concentration of the foaming agent important? What are the disadvantages of having too much foam during the flotation process? What are the disadvantages of having too little?
5. In the paper industry it is common to report the parts per million of dirt (PPM), which is calculated as one million times the area covered by dirt divided by the analyzed area. Assuming that the spots you detected had an average size of 0.01 mms and using the average # spots/cm values for the ACCEPTS and FEED samples, calculate the PPM

values for each sample. Does the ACCEPTS sample meet 50 PPM criteria for cleanliness?