MICROBIAL MINING

Overview

In this activity, students explore the role biological technology plays in mining and wastewater treatment. Students research how microorganisms are being used to treat and restore metal-contaminated waste water through direct and indirect bacterial leaching mediated by chemical reactions. In addition, they predict and explain the outcome of an oxidation-reduction reaction involving the metal iron.

Grade Band: 9-12

Topic: Wastewater Treatment

Real World Science Topics

- Microbiology
- Biomining
- Genetic Engineering
- Biodiversity

Objectives

Students will

- Explore the role biological technology plays in mining and wastewater treatment.
- Research how microorganisms are being used to treat and restore metal-contaminated waste water through direct and indirect bacterial leaching mediated by chemical reactions.
- Predict and explain the outcome of an oxidation-reduction reaction involving the metal iron.
- Explore the role genetic engineering plays in the future of biomining.
- Explore the biological diversity benefits of treated effluents to create new or enhance existing wildlife habitat.

Next Generation Science Standards (NGSS)

HS. Earth and Space Sciences *Integrates traditional science content with engineering through a Practice or Disciplinary Core Idea
HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
Science and Engineering Practices
Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2)
Disciplinary Core Ideas
Chemical Reactions Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (HS-PS1-2) Biodiversity & Humans. Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (HS-LS4-6)
Crosscutting Concepts
Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)

Time Needed: 1 – 2 Hrs.

Background Information

Why is it vitally important to manage and treat the water leaving mine sites?

A central goal of one of the Grand Challenges for Engineering in the 21st century involves combating threats to the world's water supplies and providing access to clean water. In order to ensure that the water leaving mine sites does not impact detrimentally water consumers downstream; mining companies have developed environmentally responsible water management and treatment plans. In addition, the high maintenance and disposal costs of active water treatment have generated increased interest in passive water treatment options which take advantage of natural biological, physical, or chemical processes without additional inputs.

Key Vocabulary

Biomining/Bioleaching — an approach to the extraction of desired minerals from ores. Microorganisms are used to leach out the minerals, rather than the traditional methods of extreme heat/toxic chemicals, which are harmful to the environment.

Oxidation —the process through which a chemical substance gains oxygen, loses hydrogen, or loses electrons.

Reduction — the process through which a chemical substance loses oxygen, gains hydrogen, or gains electrons.

Biodiversity — the variety of life in the world or in a particular habitat or ecosystem.

Materials & Equipment

- Computer connected to the Internet
- Chart paper
- Markers
- Post-it notes
- Copies of student handout: "Compare and Contrast Graphic Organizer"
- Copies of experiment worksheet: "Reaction of Steel Wool with Vinegar"
- Steel wool
- Vinegar
- Two 250-mL glass beakers or clear plastic cups
- Parafilm (moisture-resistant, flexible plastic) or paper lid
- Thermometer or temperature probe
- Gloves
- Safety glasses
- Lab apron

Procedure

1. **Warm-Up Activity:**
   Ask students to create a brief timeline of their day that includes each time they used water. Prompt students with ideas such as, did you brush your teeth, fill a water bottle, take a shower, or wash your hands.

   As an activator and to establish the context for the lesson show the video, Chemical versus Biological Wastewater Treatment Part I.

2. Lead the class in a discussion of the following questions:
   - What happens to the water we use everyday?
   - Why is the discharge of nitrogen and phosphorus harmful to the environment?
   - Why is sedimentation alone not sufficient to separate organic particles in mechanical wastewater treatment? How are the increased requirements met?
   - How does the process of biological treatment work?
   - How does the chemical treatment approach work?
   - How does biological purification differ from chemical purification?

3. Explain that microbiology has played an increasingly important role in mining and wastewater treatment. Microbes can help extract and neutralize metals from waste materials and be used in different steps of mining.

4. Guide students to research how microorganisms are being used to treat and restore metal-contaminated waste water through direct and indirect bacterial leaching mediated by chemical reactions. Provide the class with the student resource sheet (*Bioleaching Venn Diagram*) to begin the activity. Organize research groups of 3-4 students each. Students may use the following resources:
   - *http://www.spaceship-earth.org/REM/BRIERLEY.htm*
   - *http://www.biotecharticles.com/Applications-Article/Bioleaching-Application-of-Biotechnology-in-Mining-Industry-850.html*

5. Have students complete the Graphic Organizer in which they compare and contrast direct and indirect bioleaching methods. Randomly call on students from different groups, using equitable calling strategies, to share information they included in their Graphic Organizer. Be sure to emphasize the following key points:
   - Both direct and indirect bioleaching are used in microbial mining to extract metals from large quantities of low grade ores using microorganisms that are said to be chemolithotrophic ("rock-eating"). The bacteria obtain energy from the oxidation of inorganic substances.

- In the direct method, microorganisms directly attack minerals through an enzymatic process that involves oxidation.
- In the indirect method, the bacteria produce strong oxidizing agents, such as ferric iron, which react with metals and indirectly extract them from the ores.
- Both methods are economical and environmentally friendly. In addition, they both are employed for collecting metals from wastes or drainages.

6. Invite students to summarize their learning by placing chart paper in four corners of the room. Label them as Interesting, Different, Exciting, and Connection to My Life. Play music and ask students to wander around the room. When the music stops, ask students to gather at the closest corner and write down their ideas. Repeat the rotation and idea gathering several more times. When revisiting a corner, students can place a check next to ideas they agree with.

7. Next, introduce students to the experiment they will be conducting in small lab groups. The purpose of the experiment is to predict and explain the outcome of an oxidation-reduction reaction involving the metal iron. Students will evaluate the pros and cons of bioleaching copper with microorganisms, which involves iron oxidation reactions, versus traditional chemical methods. Students will use evidence from their lab to support their conclusion.

8. Provide each student with a copy of the lab sheet. Encourage students to hypothesize what will happen when they react steel wool with vinegar. Make sure they explain the basis for their hypothesis.

   Safety: Have students wear safety goggles, gloves and a lab apron when conducting the experiment. Make sure students are following the teacher's instructions as well all safety procedures.

9. **Evaluate: Summary**
   Invite students to record their observations and experimental data in their lab notebook, explaining whether or not their observations are consistent with their hypothesis. Students should also record their answers to the post-lab analysis questions 1-6 in their notebooks.

   Experimental Findings Include:

- Vinegar is an acid which removes the protective layer of steel wool and accelerates the oxidation of steel (iron).
- The temperature inside the second beaker gradually increases because the formation of rust is an exothermic chemical reaction, which releases energy in the form of heat to the surroundings. The newly

created bonds between single oxygen atoms and iron need less energy than the bonds between two oxygen atoms, as it is usually found in air.

- The balanced chemical equation for this chemical reaction is:
  $4Fe(s) + 3O_2(g) \rightarrow 2\ Fe_2O_3(s)$
- In the reaction shown above, iron gets oxidized since its oxidation state increases from zero to +3 and it loses three electrons. On the other hand, oxygen gains two electrons and gets reduced.

Summarize by asking students to write a tweet using a post-it note. Provide the hashtag #miniatureminer. Ask students to write a tweet, 140 characters in length, to describe the relationship between microorganisms and mining.

Extension Activity

As an extension, small groups of students will choose one of the following:

1) Explore the role genetic engineering plays in the future of biomining, or

2) Explore the biological diversity benefits of treated effluents to create new or to enhance existing wildlife habitat, as well as the risks to wildlife associated with these treatment and disposal methodologies.

Additional Resources

https://www.copper.org/publications/newsletters/innovations/2004/05producing_copper_natures_way_bioleaching.html
http://magazine.cim.org/en/technology/miniature-miners/
http://redpath-museum.mcgill.ca/Qbp/3.Conservation/impacts.htm
http://www4vip.inl.gov/research/biomining/d/biomining.pdf
http://bart.bangor.ac.uk/documents/Mining%20and%20Microbiology
http://www.scielo.cl/pdf/ejb/v5n2/a10.pdf

Name ________________________________

Student Resource: Compare and Contrast Graphic Organizer

Direct Bioleaching	Indirect Bioleaching

How are they the same?

How are they different?

Name ___________________________________

Experiment: Reaction of Steel Wool with Vinegar

Lab Sheet

Background: In this experiment, you will perform a chemical reaction between vinegar and iron in the form of steel wool. Steel wool is a bundle of very fine and flexible sharp-edged steel filaments. Steel is a metal alloy that contains iron and often some carbon. Vinegar is a dilute solution of acetic acid which is a molecule that contains the elements carbon, hydrogen, and oxygen.

Materials and Equipment

- Steel wool
- Vinegar
- Two 250 m-L glass beakers or clear plastic cups
- Parafilm (moisture-resistant, flexible plastic) or paper lid
- Thermometer or temperature probe
- Rubber gloves
- Safety glasses
- Lab apron

Hypothesis

Predict what will happen when the steel wool is reacted with the vinegar. Please explain the basis of your hypothesis.

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Instructions

1. Put on gloves, safety glasses, and a lab apron.
2. Loosen up a ball of steel wool and place it in the bottom of a 250-mL beaker or plastic cup.
3. Pour 25-mL of vinegar on to the steel wool. Then, stretch Parafilm over the top of the container or cover the container with a paper lid.
4. Swirl the beaker or cup so that all the steel wool comes in contact with the vinegar.
5. Remove the steel wool from the beaker and drain any excess vinegar.
6. Next, transfer the steel wool to a new beaker or cup and cover the container with Parafilm or a paper lid.
7. Poke a small hole in the middle of the lid and insert the thermometer or temperature probe so that it touches the base of the steel wool. Ensure that the container remains covered so no heat escapes.
8. Measure and record the initial temperature of the steel wool and then monitor the temperature over the course of the next 5 minutes. Record the temperature readings in your lab notebook in a table like the one below.
9. Complete your post-lab analysis (answers to questions 1-6, below) in your lab notebook.

Sample Data Table

Time Interval (minutes)	Temperature ($^{\circ}$C)
1	
2	
3	
4	
5	

Post-Lab Analysis Questions

1. What happened to the steel wool? Was your hypothesis correct? What are some signs that a chemical reaction took place?

2. Did the temperature inside the beaker change? If it did, can you explain why it changed?

3. Write and balance the chemical equation for the reaction that takes place in the second beaker.

4. Describe the electron-transfer process that occurs in this reaction. Which substance gets oxidized? Which substance gets reduced?

5. If you were to compare the mass of the steel wool before and after the reaction do you think there would be a change? Why or why not?

6. Recall the video warm-up from the beginning of the lesson. Now that you've seen oxidation in action, consider the pros and cons of employing the bioleaching of copper with microorganisms, which involves iron oxidation reactions, versus traditional chemical methods.