ELECTROWINNING (EW)

Removing copper from rock electrochemically

PROJECT SUMMARY:

In this project students will explore concepts in mineral processing engineering (also known as metallurgy), industrial process engineering, and chemical engineering to iteratively improve the design of an electrochemical copper refining process. The basic process uses a solvent (acetic acid) to dissolve copper ions from an oxide copper mineral (malachite). The solution is then placed in an electrolysis cell and an electric current is used to move copper ions through the solution and deposit them as copper metal onto a cathode, industry calls this process "electrowinning." In copper refining the electrowinning process is repeated several times to produce 99.999% pure copper. This project mimics the first electrowinning pass on a small scale.

PROJECT GOALS:

- DESIGN an effective mineral processing circuit using an iterative design process.
- DEVELOP a set of requirements and process flow diagram for the final processing circuit design.
- DOCUMENT the design process in a short technical report detailing the final processing circuit design and steps taken to reach the final design.

PROJECT PLANNING:

- Teams of two to three work best.
- Plan for at least 2 to 4 hours of class-time. The project can be extended with extra modules.
- Students should be familiar with safe chemical handling practices.
- Malachite beads are used for the oxide ore. They can be bought easily online but beware of fake malachite. An easy test to find fake malachite is to immerse a bead in vinegar overnight. Real malachite will start to turn the vinegar a light blue color. Real malachite beads are usually random pebble shapes and almost never spheres.

OTHER OUTCOMES

- Students utilize knowledge of basic chemistry to improve process.
- Students gain familiarity with iterative design process. (Design, Test, Evaluate).
- Students understand "real world" conditions can interfere with predicted outcomes.
- Students create a data collection method that is effective and works with their workflow.

ENGINEERING CONNECTIONS:

Combines components of

- Metallurgy (mineral processing engineering)
- Chemical Engineering
- Industrial Process Engineering

ENGINEERING IDEAS

- Students understand the concept of a "process flow diagram."
- Students become familiar with the concept of a "Safety is everyone's job."
- Students use analytical equipment to quantify results of design changes.
- Students record and compare test data.

STANDARDS ADDRESSED

CTE Career Preparation Standards: Engineering 15.0000.00

STANDARD 1.0 INVESTIGATE THE FIELD OF ENGINEERING TO ADDRESS THE NEEDS OF A GLOBAL SOCIETY

- 1.2 Recognize that engineers solve a wide range of problems involving innovation, cost reduction, and more efficient/effective processes.
- 1.4 Explore emerging fields in engineering and challenges to future work and future life [i.e., drones, electric cars, autonomous cars, AI, IoT, Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Additive Manufacturing (AM), Smart City design, Automation, Machine Learning (ML), M2M (Machine-to-Machine), H2M (Human-to-Machines) , etc.]
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STANDARD 2.0 CREATE ENGINEERING SOLUTIONS BY APPLYING A STRUCTURED PROBLEM-SOLVING/DECISION-MAKING PROCESS

- 2.1 Identify the problem.
- 2.2 Develop a problem statement based on facts, research, and experience.
- 2.3 Explore possible issues or options to the problem.
- 2.4 Select the best solution within the constraints and criteria.
- 2.5 Develop a prototype or model to test the selected solution.
- 2.6 Implement the solution.
- 2.7 Evaluate the solution, and revise or repeat if necessary (i.e., Are there other solutions, better solutions, or cheaper solutions? etc.).
- 2.8 Document and report all results.

STANDARD 3.0 APPLY Mathematical Laws and Principles Relevant to Engineering Technology

- 3.1 Use basic mathematical functions and tools (i.e., Google Sheets, Excel, graphing calculator, etc.)
- 3.2 Use data collection and analysis to display data and verify its accuracy

STANDARD 5.0 APPLY TECHNOLOGY AND TOOLS TO ENGINEERING SOLUTIONS

- 5.4 Use software tools to solve, model, analyze, and/or design solutions to engineering problems (i.e., SOLIDWORKS, AutoCAD, On-shape, Fusion360, Google Sheets, Excel, etc.)
- 5.5 Identify hazards, risks, and incidents related to tools and equipment.
- 5.6 Practice safe use of tools, machines, equipment, and materials (i.e., OSHA, SDS sheets, PPE, etc.).

STANDARD 6.0 APPLY COMMUNICATION SKILLS TO ENGINEERING PROJECTS

- 6.1 Apply technical writing skills and use visual aids to present critical information in reports (i.e., results/outcomes, conclusions, future work recommendations, etc.).
- 6.2 Utilize the three stages of oral presentation (e.g., planning, practicing, and presenting).
- 6.3 Apply communication skills, including listening skills, with project teams, project managers, clientele, and/or contractors.
- 6.4 Explain the importance of multiculturalism in creative and professional decision-making (e.g., better decisions based on different views, perspectives, ideas, and proposals; fosters critical thinking, analysis, and collaboration).

STANDARD 7.0 APPLY PROJECT MANAGEMENT TOOLS AND TECHNIQUES TO ENGINEERING SOLUTIONS

- 7.5 Document and present project results/outcomes as appropriate.
- 7.6 Analyze the project from various perspectives (i.e., sustainability, political, economic, health and safety perspectives, etc.).

English Language Arts Standards

11-12.W.2 Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.

a. Introduce a topic; organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include formatting, graphics, and multimedia when useful for comprehension.
b. Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic.
c. Use appropriate and varied transitions and syntax to link the major sections of the text, create cohesion, and clarify the relationships among complex ideas and concepts.
d. Use precise language, domain-specific vocabulary, and rhetorical techniques to manage the complexity of the topic.
e. Establish and maintain a style and tone appropriate to the norms and conventions of the discipline in which they are writing.
f. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

11-12.W.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (Grade-specific expectations for writing types are defined in standards 1–3 above.)

11-12.W.10 Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences.

EW PROCESS

SAFETY PRECAUTIONS

1. PERSONAL PROTECTIVE EQUIPMENT (PPE) REQUIRED: Eye protection, gloves.
2. CHEMICAL HAZARD: This process produces a copper vinegar solution that contains aqueous copper acetate, $Cu_2(CO_2CH_3)_4(H_2O)_2$. Concentrated copper acetate is a health and biologic hazard. DO NOT DRINK. Wash hands after use. If vinegar solution comes into contact with your eyes, remove contacts if worn, flush eyes under running water for 15 minutes, and seek medical attention. Do not dispose of copper-vinegar solution in waters that contain aquatic life.
3. EYE HAZARD: Small pieces of rock and/or chemical solution can become airborne during this process. EYE PROTECTION IS REQUIRED FOR STUDENTS USING THE MORTAR AND PESTLE.
4. ELECTRIC SHOCK: This process carries a low risk of electric shock. Disconnect all circuits before modifying parts of the circuit.

TODAY'S GOAL

The goal today is to design an electrowinning circuit that will produce the most copper by mass in the given time. Your team will do this by modifying the simple EW process that was demonstrated today.

MATERIALS

Each team will be given the following materials from which to design their EW circuit.

Item	Use
SAFETY EQUIPMENT	
Eye Protection	To keep eyes safe
Gloves	To protect hands
Sanitizer wipes	To clean Eye Protection and hands
Basic SXEW Equipment	
100ml White Vinegar (Acetic Acid, 5%)	To dissolve copper oxide minerals
2g Copper oxide ore (malachite beads/chunks)	To provide copper oxide for dissolution
Steel "dog tag"	To act as the cathode for plating copper
Alligator clips	To hold anode and cathode
2 Plastic cups	To act as reaction vessel/electrowinning cell
Funnel	To hold filter paper
Filter paper	To keep ore and solution separate
Copper square	To use as anode in electrowinning cell
Paper Towels	To clean up spills
Plastic Bags	To hold 'waste' (used gloves, towels, etc.)
Data sheet	To record experiment data
SXEW Equipment Options	
Emery cloth	To clean anode/prep cathode
9v battery and holder	As a power source option
2 AA batteries and holder	As a power source option
Lever wire nut	To connect battery holders/alligator clips
Mortar and pestle	As an "ore dressing" option
2 Clips	Option to control anode and cathode position
Tape	Option to control anode and cathode position
Equipment for whole class to share	
Mass balance (grams)	To measure the final mass of the cathode
Waste bucket	To collect used copper-vinegar solution

OUR TEAM

Record your team member's names below. Do not forget your own name.	
Metallurgist 1:	
Metallurgist 2:	
Metallurgist 3:	
Metallurgist 4:	

USEFUL TERMS

Anode: The part of the electrowinning cell at which point an oxidation reaction occurs. In our experiment this is the penny attached to the positive lead.

Cathode: The part of the electrowinning cell at which point a reduction reaction occurs. This is where the metal plates out. In our experiment, this is the nickel attached to the negative lead.

Electrowinning: A term used in the mining industry for the process that removes a desired element from solution by passing a current through the solution to attract the desired element onto a receiver cathode.

Leaching: The process by which desired minerals are dissolved by a solvent (such as an acid) which is pored over ore and then collected. At the end of this process the solvent contains the desired minerals.

Ore: a rock/mineral which contains or is itself something that is useful to humans.

Ore Dressing: The process in which ore is prepared for refining. Most often this involves crushing the ore to make it smaller. Ore dressing is designed to improve the effectiveness of subsequent processing steps.

Oxidation: The process by which a material reacts with oxygen to form a compound with it. The most famous of these reactions is iron rust.

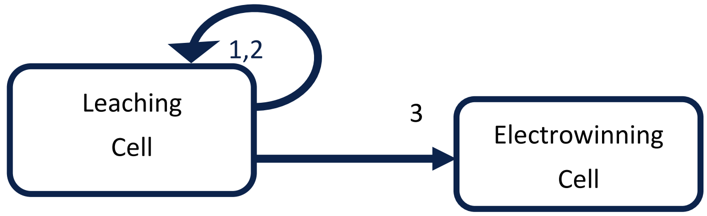
Oxide: A mineral that results from the oxidation (commonly known as rust) of a material.

Process Flow Diagram (flowsheet): A diagram used in process engineering to outline the general flow of plant process and equipment.

Solvent Extraction: A term used in the mining industry for the process that uses an organic solvent, to preferentially remove desired metal ions from and acid solution.

GENERALIZED PROCESS

The Process Flow Diagram for the demonstrated experiment is below.



This flow diagram is quite simple. The process in the leaching cell is carried out twice as indicated by the numbered circular arrow. After that the solution moves on to the Electrowinning process.

What changes can you make to your Leaching and Electrowinning processes to improve them? Do you need to add another process? Maybe add more cycles through an existing process? What if you modify the existing process to improve them?

Put on your metallurgist hats and figure this out.

Simple Leaching Cell Process

Equipment:

- Funnel
- Filter paper
- 2g oxide ore
- 100ml white vinegar (5% acetic acid)
- 2 Plastic cups

Process:

1. Insert funnel into plastic cup.

2. Insert filter paper into funnel.

3. Pour oxide ore into filter paper.

4. Pour 100ml of vinegar over oxide ore.

5. Wait for vinegar to percolate though filter.

6. Move funnel over to second cup and repeat the process twice.

7. Move filter to second cup to drain and prepare cup containing copper-vinegar solution for electrowinning.

Simple Electrowinning Cell Process

IMPORTANT: These instructions are for the basic process. Students should not just copy the process as performed! THE STUDENT'S JOB IS TO IMPROVE UPON THIS!

Equipment:

- Record sheet
- Cup containing copper-vinegar solution from Leaching step
- Alligator clips
- Steel dog tag (cathode)
- Measuring boat
- Lever wire nut
- Copper square (anode)
- 9v battery and holder
- 2 clips

Process:

1. Bring steel tag to balance at the front.

2. Zero the balance. Place steel tag on weighing boat and record the mass.

3. Return to experiment station.

4.Connect steel tag to negative "black" wire and alligator clip.

5. Connect copper square to positive "red" wire and alligator clip.

6. Open red lever on lever wire nut and insert red wire connected to alligator clip, lower red lever to secure the wire.

7. On the same side of the lever nut, open blue lever on wire nut and insert black wire connected to alligator clip, lower blue lever to secure the wire.

8. Connect the 9v battery holder to the lever nut in the same manner red lever to red wire, blue lever to black wire. DO NOT CONNECT THE BATTERY YET!

9. Insert the copper square "anode" into the copper vinegar solution. Do your best to keep the alligator clip dry. Secure the wire to the cup with a clip.

10. Insert the dog tag "cathode" into the copper vinegar solution opposite the "anode." Do your best to keep the alligator clip dry.

11. Check that the cathode and anode are not touching and that all wires are connected.

12. Connect the 9v battery to the battery holder.

13. Let the circuit run for several minutes. You should see bubbles forming on the negative "cathode."

14. Disconnect battery.

15. Remove the steel tag "cathode" from alligator clip and place on paper towel to dry.

16. Once dry, bring the steel tag to the balance.

17. Zero the balance. Place the steel tag on the balance and record the mass.

19. Use math to subtract the initial mass of the dog tag from the final mass of the steel tag to find the amount of copper produced.

TODAY'S EXPERIMENT

Your team's task is to modify the generalized process above to obtain more copper in the time given.

1. **Equipment and safety gear.**
    a. Collect and appropriate size of gloves from the boxes provided.
    b. Collect a pair of Safety Glasses.
    c. Put on gloves and safety glasses.

2. **Discuss with you team ways to improve the process.**
    a. Decide which optional materials you would like to use in your process.
        i. Adding process to the process flow.
            1. Mortar and pestle (to crush oxide ore).
            2. Increase/decrease number of cycles through leech process.
        ii. Change type of current supply.
            1. 9v battery and holder.
            2. 2 AA batteries and holder.
        iii. Change geometry of electrowinning cell.
            1. Tape to hold anode and cathode in place.
            2. Clips to hold anode and cathode in place.
            3. Other strategies?
        iv. Other? Using the materials provided, are there other things you could do to improve your copper production?
    b. Create your team's new process flow diagram.
3. **Once the signal is given, begin your experiment.**
    a. Be sure to follow safe chemical and electricity handling practices.
4. **At the buzzer, disconnect your battery and remove your cathode (dog tag) from your electrowinning cell and proceed to the balance to mass it and find out how much copper you have refined.**

    a. You may dry your cathode while you cleanup.

5. **Cleanup**
    a. Carefully bring you copper vinegar solution to the waste bucket and pour the solution into the bucket. Put filter paper and remaining oxide ore into plastic bag provided.
    b. Wipe down everything with paper towels. Put used gloves in plastic bag provided.
    c. Remove gloves and put them in the plastic bags provided.
    d. Remove safety glasses, wipe them down with sanitizing wipe, and return the glasses to the box. Dispose of sanitizing wipe in bag provided.
    e. WASH YOUR HANDS (use a wipe if no sink is available).
6. **Present your Final Process and results to the group.**

RECORD DATA

Record the data collected during your EW process on this sheet.

Draw your new Process Flow Diagram below

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Notes: Record what choices you made.

i.e. Length of time spent leaching, batteries used, amount of time spent electrowinning, etc.

Before SXEW Process		**After SXEW Process**	
Mass of Cathode (steel tag) alone BEFORE experiment (g)		**Mass of cathode (steel tag) alone AFTER experiment(g)**	

Total Copper Collected	
Mass of Cathode **AFTER** Experiment (g)	
-	
Mass of Cathode **BEFORE** Experiment (g)	
=	
Copper Produced during Experiment (g)	

CLEAN UP FOR YOUR CLASS

The copper acetate solution made during this experiment is poisonous to plants and aquatic life. Do not dispose of it in storm drain systems that drain into lakes, rivers, or streams. The solution is very weak so it can be disposed of by slowly pouring it into a drain connected to a sewer system while water is running into the drain. Alternatively, the properly labeled solution can be stored for later use in copper plating experiments.

The remaining malachite can be dried and collected for later use. If it is mostly dust, carefully seal it in a bag and dispose of it.

Towels, filter paper, and soiled gloves should be collected and disposed of.

EXTENSIONS

- Industrial Process extension: This same process can be used to electroplate small metallic items with copper. However, creating a nice, shiny, long lasting copper coating on an object can be difficult. Concentration of the copper-vinegar solution, consistent current flow, and the geometry of the electroplating cell all come into play. The experiment could be extended to further refine the process to produce a purer copper at the cathode with a pretty result.
- Chemistry Extension: Students confident in their chemistry skills could calculate the stoichiometry of the reaction. It is possible to get an estimate for how much copper the vinegar is capable of dissolving for a given volume. From this, students could calculate an estimate for how much copper will be plated out onto the cathode. They may find this a challenge as malachite may contain impurities and may not be pure $Cu_2CO_3(OH)_2$.
- Further Mineral Processing extension: This same process can be used with other copper oxide minerals. If you can find chrysocolla, cuprite, or azurite, students could compare the effectiveness of vinegar as a solvent for those minerals. Alternatively, malachite that is still attached (hosted) on a rock sample could be used. Students may find that the rock the malachite is attached to can affect the amount of copper produced. For example, malachite hosted on limestone will use up the vinegar very quickly (as it will react with the limestone as well) and result in a very weak copper-vinegar solution.
- Waste Prevention Extension: To encourage good lab hygiene and get students to think about the waste produced when people make things, have each team collect and store all of the waste they generate during the unit (paper towels, gloves, filter papers). Teams should try to minimize the amount of waste they create, which means that they need to be careful and avoid “industrial accidents” (spilling the cup full of vinegar, etc.). Perhaps, the best process is not the one that produces the most copper in a short amount of time, but the one that produces the least waste.