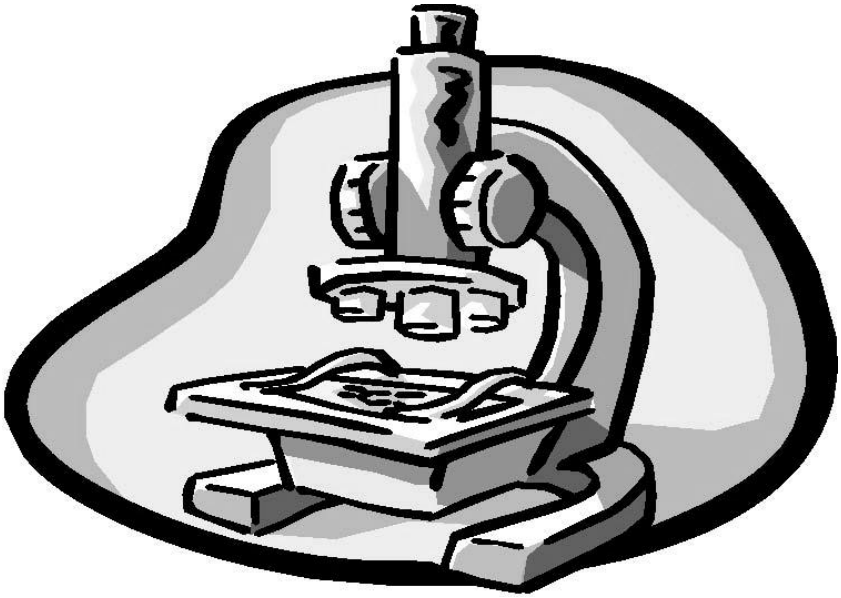
FROM EARTH TO METAL

Copper Production in Arizona



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IMPORTANT NOTICE

COPPER PRODUCTION

Extracting Copper from Sulfide Ores

Geologists are scientists who study the earth's history through its rocks and minerals (crystals in rocks). Before mining can begin, geologists must locate an area that contains minerals that can be mined and processed at a profit. This area is then called an **ore deposit.**

When geologists believe they have located an ore deposit, test holes are drilled to determine the size and location of the deposit. This is called **exploration drilling or diamond drilling.** A rock containing enough copper to be mined at profit is called **copper ore.** When a copper ore deposit is deep within the earth, underground mining methods must be used to get to it. When a copper ore deposit is close to the earth's surface, an **open pit or surface mine** can be developed. In an open pit mine, explosives are used to break and loosen the rock. Large power shovels load the ore, frequently in the form of large boulders, into trucks where it is taken to the **primary crusher.**

Copper ore that contains copper minerals with sulfur is called a **sulfide ore.** The copper must be separated from the sulfur and other impurities to make it usable. The first step in separating the copper from a sulfide ore is called **crushing.** It is here that large rock is crushed into pieces as small as %". The crushed ore is then transported to the **mill.**

The ore is put into **ball and/or rod mills.** A ball or rod mill is a very large, turning drum in which the ore is crushed into a powder by tumbling the ore with steel balls or rods and liquid, mostly water. The resulting soup-like mixture of powdered rock and liquid is called **slurry.** Additional chemicals are added to the slurry to prepare the copper mineral to separate from the host rock.

The slurry is then pumped into a **flotation separator.** Air is bubbled through the slurry to make foam called **froth.** The copper mineral particles stick to the froth bubbles while the waste rock, called **tailing,** sinks to the bottom of the separator. The froth containing copper is scraped off the mixture. It is reground and floated several times to allow the froth to hold more pure copper and fewer impurities each time. Copper mineral that is very pure is called **copper concentrate** and may contain as much as 30% copper. Finally, the copper concentrate is filtered, dried and sent to a **smelter.**

Most of the impurities, such as sulfur and iron, left in copper after the flotation process, can be removed through the process **of smelting.** In smelting, the copper concentrate goes through a **flash furnace** that shoots flames over it, changing the copper concentrate into a molten mass. The heat helps drive off some of the sulfur in the form of **sulfur dioxide gas.** Iron rises to the top of the molten mass in the form of iron-silicate glass called **slag.** The slag is skimmed off, cooled, crushed, and smelted again to recover the copper remaining in it. The mixture, called **copper matte,** contains from 50% to 60% copper plus sulfur. It still has impurities in the form of other metals such as gold, silver and nickel.

Next, blowers force **oxygen** through the molten copper matte. The oxygen combines with the rest of the sulfur to form **sulfur dioxide gas.** The sulfur dioxide gas is collected and added to water to form **sulfuric acid. Silica** (sand) is then added to the molten mixture.

The silica combines with the iron to form more **slag,** which is again skimmed from the surface. The resulting leftover mixture, called **blister copper,** is 97% to 99.5% pure copper. The blister

copper is cooled in molds that are 3 feet square and 3 inches thick. These molds of blister copper are called **anodes** and weigh 750 lbs.

The copper anodes are further purified or **refined** through the process of **electrolysis.** Alternating copper anodes and starter sheets are hung in tanks containing **copper sulfate** and a weak sulfuric acid solution. Copper from the anodes is dissolved into the solution, and when an electric current is passed through the tanks, the dissolved copper is **plated** onto the starter sheets forming **cathodes.**

Over a period of about three weeks, the original **starter sheets** increase in weight from about 10 pounds to 100-300 pounds. The copper deposited on the **cathodes** is more than 99.9% pure and can now be sold to and used by manufacturing industries. Most of the impurities from the anodes settle to the bottom of the tank and form **sludge.** Small amounts of gold, silver and other metals are recovered from the sludge.

Extracting Copper from Oxide Ores

Copper minerals that do not contain sulfur are copper oxides. The sulfur has been naturally leached from the host rock by oxygen in the atmosphere or by precipitation. Extracting copper from oxide ores typically involves leaching the ores with an acidic solution in which the copper dissolves. In heap leaching, large piles of oxide ore are placed on a lined surface protected with heavy polypropylene and are literally sprayed by a sprinkler system or soaked by a drip system with a weak sulfuric acid leach solution. Over time the leach solution percolates down through the heap, picking up copper as it travels along. A central drainage system collects the run-off at the bottom of the heap. The leach solution flows from the dump's base as pregnant leach solution (PLS), drains into a collection pond, and is pumped to a feed pond for the solvent extraction (SX/EW) plant.

At the SX plant, the PLS solution is mixed with an organic chemical (one that contains carbon) and kerosene (a thin oil). This causes an ion exchange between the two solutions. The PLS loses copper ions and the organic gains copper ions. After the ion exchange, the lighter solution (a mixture of the organic and kerosene) floats on top of the heavier leach solution much like oil floats on water. Next, a stronger sulfuric acid-water solution, lean electrolyte, is mixed with the organic. This forces the copper to move from the organic into the electrolyte making rich electrolyte. Once the leach solution is "emptied" of copper ions it is recycled back to the heaps to be used again for leaching.

Finally, the rich electrolyte is pumped to the electrowinning plant (EW). EW or electrowinning is an electro-chemical process in which copper from an electrolyte is plated onto a starter sheet. The electrolyte is put into tanks or cells that contain alternating sheets of lead (anodes) and stainless steel, titanium, or copper (starter sheets). The materials used as starter sheets differ from mine to mine. As electricity is passed through the cells, two chemical reactions take place. In the first reaction, oxygen bubbles form on the lead sheets (anodes) and electrons are released. In the second reaction, electrons from the lead move through the electrical circuit causing the copper in the solution to move out and collect or plate onto the starter sheets forming cathodes of 99.99+% pure copper. The cathodes either can be stripped from the starter sheets or collected and sold as is or transported directly to the rod plant for continuous casting. At the rod plant, this virtually pure copper (99.99+%) is melted and shaped into round, thick rod (approximately %" in diameter) and packaged as huge coils. Manufacturing industries use this copper rod for a variety of purposes.

The Milling Process Extracting Copper from Sulfide Ores

Objective: Students will demonstrate the process of milling

Problem: What is the purpose of milling?

Hypothesis:

Background Information:

From the crushing process, pieces of rock containing copper sulfide ore, $^{1}/z$" to 8" in diameter, are transported to a mill. Here the crushed sulfide ore is put into drums called mills, which contain liquids and balls or rods. As the drum turns, the steel balls or rods fall against the rock and break it into smaller pieces. The mixture of powdered rock and water that results from the milling is called slurry. Additional chemicals are added to the slurry to prepare the copper mineral for separation from the powdered rock when it moves on to the flotation separator.

Materials:	
Crushed Sulfide Ore (Sandstone if ore isn't available)	Steel Shot 1/4"-3/8" (available from K-mart, Wal-Mart, or hunting store)
Water	Plastic Jar or Coffee Can, with lid
1/2 centimeter (1/8"-1/4") Wire Screen	Large Container
Towel	Plastic Cup

Procedure:

1. Fill the jar one third with crushed sulfide ore and steel shot - **KEEP A FEW PIECES OF SULFIDE ORE AND STEEL SHOT OUT TO BE USED FOR COMPARISON DURING OBSERVATIONS.**
2. Add enough water to cover the ore and shot so that it is submerged about one centimeter. Cover the jar securely with lid.
3. Wrap jar in a towel and shake the jar for 2 minutes.
4. Screen the mixture by pouring it over the 1/2 cm wire screen. Be sure you have a large container to catch the water and smaller pieces beneath the screen.
5. Record your observations in Data Table 1.1.
6. Return oversize pieces of rock and the steel shot to the jar and recycle the water by pouring it from the larger container back into the milling jar. Repeat steps 3-5 two more times, recording your observations.

7. Add about a tablespoon of water to the jar to retrieve settled ore. Swish the mixture around and pour into the plastic cup.
8. Save the slurry (screened liquid and ore) by pouring into a plastic cup. Set aside for use in the flotation process.
9. Separate the large pieces of ore from the steel shot. Place the steel shot on a paper towel to dry.

Observations: Record noticeable changes in the size and shape of the rock and steel shot. **Data Table 1.1** Changes in the Sulfide Ore and Steel Shot
Trial 1:
Trial 2:
Trial 3:

Analysis:
1. What is the purpose of the jar and what does it represent?
2. What is the purpose of the steel shot and what does it represent?
3. What is the purpose of the screen?

Conclusions: Why is the milling process necessary?

FROTH FLOTATION
EXTRACTING COPPER FROM SULFIDE ORES

Objective: Students will demonstrate the froth flotation process involved in extracting copper from sulfide ore.

Problem: What is the purpose of froth flotation?

Hypothesis:

Background Information:

The end product of the milling process is called **slurry.** The copper minerals are removed from the slurry through the froth flotation process. Chemicals called reagents are added to the slurry and adhere to the copper minerals only, not the other rock particles. The chemical/copper combinations are "air seeking", so that when air is forced through the slurry, the combinations attach to air bubbles and float to the top. This combination is skimmed off as froth, hence the name "froth flotation".

The copper concentrate is cleaned, dewatered, filtered, and dried, and this product is called **copper concentrate.**

The waste rock, called **tailing,** is left behind at the bottom of the flotation tank. If you think about the rock in the flotation process as a room with 100 people, at the end of the flotation process there would be only .6% of one person left in the room (copper concentrate). The other 99.4% of the people can be thought of as tailing. The **tailing** is pumped to a **tailings pond** and dewatered. The water is recycled back into the concentrating process.

Materials:	
"Slurry" Mixture Of Water And Ore from The Milling Lab	8 oz. Plastic Cup
Straw	Paper Towel
Mr. Bubble	Index Card

Procedure:

1. Fill the cup half way with the "slurry" mixture.
2. Pour Mr. Bubble into slurry.
3. Place the straw into the mixture and blow gently.
4. Observe and record all observations in Data Table 1.2.
5. Scrape off the bubbles with the index card and place on the paper towel to dry.

6. Repeat the process 3 more times and record your observations after each time.

Observations: **Data Table 1.2** Observations of the Froth Flotation Process
What did you observe collecting onto the bubbles?
Trial 1:
Trial 2:
Trial 3:
Trial 4:

Analysis:
1. What is the purpose of the bubbles?
2. Explain how this process resembles the actual froth flotation process.
3. Is all the ore collected after a few trials? Explain your answer

Conclusions:
1. What is the purpose of froth flotation?
2. Why didn't the copper ore stay on the bottom?
3. What happens to the waste (tailing)?
4. How else could these tailings be used rather than being used to build tailings dams?
5. Where does the collected copper concentrate go from here?
6. Name the waste produced during the smelting process.
7. Where does the waste go from the smelter?

THE LEACHING PROCESS
EXTRACTING COPPER FROM OXIDE ORES

Objective: The students will demonstrate the process of leaching copper from its ore.

Problem: What is the purpose of leaching?

Hypothesis:

Background Information:

Leaching is the process of separating minerals from a rock by dissolving the minerals in a liquid. The copper industry uses leaching to remove the copper from oxide ore and some sulfide ore. This is done by spraying or dripping a weak sulfuric acid solution over a large bed of ore. As the acid percolates through the rock, some of the copper in the rock dissolves into the acid. This **pregnant leach solution (PLS)** is stored in large open ponds until it is pumped to the **SX/EW (solvent extraction electro-winning plant)** where the copper is removed from the acid solution.

Materials:	
Copper Oxide	Funnel
Filter Paper (coffee filters)	White vinegar (acetic acid)
Two Jars or Plastic Cups	Paper Towels (for clean up)

Procedure:

1. Prepare the filter paper to fit inside the funnel. This is done by folding the circular paper in half and then folding it into quarters. Open the paper so that it forms a cone.
2. Three sides of the paper will make up part of the cone and one side of the paper will make up the other part of the cone. Place the cone inside the funnel.
3. Fill the funnel three-quarters full with the crushed copper oxide.
4. Hold the funnel with copper oxide inside a cup. Gently pour the leaching solution (vinegar) through the funnel. Put the funnel into a **second cup** and pour the leaching solution from the first cup through the rocks again. Repeat this step several times to make the leaching solution with dissolved copper as strong as possible. A greenish/blue solution indicates an increasing concentration of copper.
5. Record changes in solution after each pour in Data Table 1.3.

Observations: **Data Table 1.3** Changes in Leached Solution
Pour 1:
Pour 2:
Pour 3:
Pour 4:
Pour 5:
Pour 6:
Pour 7:

Analysis:

1. Describe the purpose of the vinegar.

2. What do the changes in the solution indicate?

Conclusions:

1. What is the purpose of leaching?

2. Describe the leaching process.

THE ELECTROWINNING PROCESS
EXTRACTING COPPER FROM OXIDE ORE

Objective: The students will demonstrate the electrowinning process.

Problem: How is copper ore recovered in the electrowinning process?

Hypothesis:

Background Information:

As a weak sulfuric acid solution is percolated through a bed of copper oxide ore, the copper in the rock dissolves into the **pregnant leach solution (PLS).** The **PLS** is mixed with an **organic chemical,** which causes the leach solution to lose copper ions (refer to description of "Copper Production of Oxide Ores") and the organic solution to gain copper ions. Next, this "loaded" organic solution is mixed with a **lean electrolyte** (sulfuric acid-water solution) that forces the copper to move from the loaded organic solution and mix with the lean electrolyte to form a copper sulfate solution or **rich electrolyte,** which is deep blue. The stripped organic solution is recycled to be reloaded with copper ions. Finally, the **rich electrolyte** is put into tanks containing alternating **lead anodes** and **stainless steel, titanium, or copper starter sheets.** As electricity is passed through the tanks, electrons are released from the lead sheets (anodes) and move into the electrolyte. This causes the copper ions to move out of the electrolyte and collect directly onto the copper starter sheets to form cathodes.

The cathodes produced by the **SX/EW** process are 99.99++% pure copper. Remember our analogy of the 100 people in a room? Similarly, like sulfide ore the average grade of oxide ore is .6%, but unlike sulfide ore, 99.99++% pure copper is produced after just three processes (leaching, solvent extraction, and electrowinning). Everyone in the room (100 people) would be wearing copper at the end of the process, and there would be no people representing tailing. No milling, flotation, smelting, copper anodes, or electrolytic refining would be used to produce copper from oxide ore.

Materials:	
Pregnant Leach Solution from Leaching Process	Lead Fishing Weight
2 Insulated Copper Wires (8 In.) with Alligator Clips (available at Radio Shack)	Stainless Steel Teaspoon
1.5 Volt Battery and Battery Holder	Steel Wool

Procedure:

1. Filter oxide ore back out of solution as you did in the leaching process.

2. **C**lean all battery contacts, alligator clips, and the lead weight by rubbing them with the steel wool.
3. Place the battery in the battery holder.
4. Use alligator clips to clip the insulated wire to the spoon and the cathode or negative (-) terminal of the battery.
5. Use alligator clips to connect the insulated wire to the lead weight and the anode or positive (+) terminal of the battery.
6. Suspend the spoon and the lead weight in the rich electrolyte so they do not touch each other and let sit until you start seeing a change beginning on the spoon. Track the time.
7. Observe and record any changes on the spoon on Data Table 1.4.
8. Switch the wires so that the positive (+) battery terminal is attached to the spoon and the negative (-) battery terminal is attached to the lead weight.
9. Record your observations in Data table 1.4.
10. Before returning materials to the kit, be sure to clean the lead weight, the battery contacts, and alligator clips with the steel wool

Observations: **Data Table 1.4** Changes on the Spoon
Observations from Setup 1:
Observations from Setup 2:
Were the copper ions (Cu^{+}) attracted to the anode (+ terminal) or the cathode (- terminal): a. During the first observation? How do you know? b. During the second observation? How do you know?

Analysis:

1. How long did you leave the spoon in the solution?

2. Would a longer time make a thicker coating?

3. What would happen if you added more solution?

4. Explain what happened when the wires were switched. Why?

Conclusions:

1. Describe how the copper from oxide ore is recovered in the solvent extraction and electrowinning plants.

2. Compare and contrast the electrowinning and electrolytic refining processes of copper oxide and copper sulfide ores. Use any information from this and other labs to assist you, including the background information.