Task 3. Value-added Uses for Copper Smelting Slag 2022

Proposed by Freeport-McMoRan

Background

Copper smelting is a high-temperature process that separates elemental copper from copper concentrates. Smelting leaves behind "slag" from the refining process. Once it leaves the smelter, the slag is poured onto the slag stockpile and is cooled in layers. As part of stockpile management, a dozer is periodically used on the stockpile to manage material deposition. The result of this is that the slag is broken into granular pieces of varying size

Slag has historically been managed as waste, but where economically feasible (i.e., if the cost of transporting it can be offset by the cost of the application), it is typically crushed for use in abrasives, roofing granules, road-base construction, railroad ballast, and aggregate fillers in concrete. These uses have not always taken advantage of the chemical content and unique properties of the slag that may add value to its use.

Adding Value

To support a more circular economy, Freeport-McMoRan is seeking uses for the large volumes of copper smelter slag that will capitalize on its unique composition and properties, thereby improving its salability, reducing the mining of materials with similar properties, and reducing the amount of slag that must be stored on site.

Composition and properties that may add value to the slag include: recovering economically valuable metals/materials and making use of the slag's enhanced electromagnetic interference shielding properties[1], its ability to increase compressive and flexural strengths of concrete, its low moisture absorption (and hence, improved drainage), and other properties.

Teams are urged to explore processes that will improve properties of the slag and add value to its use beyond abrasives and fillers. For example, when certain additives are combined with copper smelting slag, its pozzolanic properties increase, making it a concrete additive that may serve as a fly ash substitute. With coal mines closing, concrete manufacturers have been searching for a substitute for fly ash, making this a potentially valuable product for the concrete industry.

Slag Content

The focus of copper smelting has been to maximize copper recovery; all other metals are considered impurities that remain in the slag. The smelting process leaves behind iron silicate (approximately 40% of the slag) and significant amounts of SiO_2, FeO, CaO, and Al_2O_3 as well as small amounts of copper, zinc, titanium, and lead[2].

Smelting Process

Teams are encouraged to explore the copper smelting process to further understand the nature and properties of the slag. Freeport-McMoRan uses the IsaSmelt™ technology for the primary furnace and the ELKEM electric furnace for the secondary furnace, along with four Hoboken style converters, two oxygen plants and an acid plant that is used to treat all process gases to maintain air quality standards.[3, 4, 5]

After smelting, the slag is poured on an outdoor pile to air-cool under ambient temperatures. At that point, the slag can be used for your team's value-added application.

Problem Statement

Your team will research, evaluate, design, and demonstrate a method for either:

1. recovering economically valuable materials for copper smelting slag or
2. producing a useful product from copper smelting slag that makes use of its unique properties

for a smelting operation that smelts one million tons of copper concentrate each year, with an average copper grade of 28%.

Teams are encouraged to:

- Study current/former uses of copper smelter slag;
- Investigate new uses for slag that capitalize on its unique properties;
- Consider the logistics/economics of recovering and transporting the material from possibly remote areas.
- Consider making modifications to the smelting process at Freeport-McMoRan's Miami, AZ site that would produce a more valuable slag.

Ideally, the proposed solution would have the following benefits.

- Capitalize on the unique properties of the slag
- Use tonnages of copper smelting slag that meet smelting slag production rates.
- Serve a practical use to society
- Provide a permanent destination for the slag
- Achieve a chemically stable state that will not leach out minerals or metals
- Be cost effective (does not need to be profitable to be cost effective)

Design Considerations

Your proposed design should provide specific details and outcomes as follows:

- Describe the product, including how it is produced, how it is valuable to society, and why people would use it instead of current similar products.
- Describe how your solution makes use of the unique properties and composition of copper smelting slag.
- Determine quantities and proportions of slag in the product and establish that your slag use rates meets slag production rates, based on the smelting operation described in the problem statement.
- Develop a procedure to modify the Miami, AZ smelting process that would increase the value of the slag produced (optional).
- Provide a process-flow diagram, complete with quantified inputs/outputs for the designed process.
- Reflect on alternative designs and situations in which those designs might be more viable than your chosen design, recalling that an optimal solution depends on outside factors–the "best" design may be dependent on region and may change over time.
- Report TCLP test results, if applicable. None of the RCRA eight metals should exceed the detection limit.
- Report ASTM tests, if needed. For building materials, final products must pass ASTM tests for the targeted building material and efflorescent test, when applicable.
- Report additional tests, as needed, to confirm the integrity and/or environmental safety of the product.
- Identify any waste products or by-products that will be produced.

- Present an engineering analysis on the ability to scale up the process. Present a Techno-Economic Analysis (a.k.a. Techno-Economic Assessment) to construct a full-scale plant. State the number of expected tons processed per day. The TEA will include your estimate of capital costs (CAPEX) and operational costs (OPEX) for a full-scale solution and appropriate graphical representation of your cost data.
    - Include a financial analysis of any potential product salable value. Note that plant location in reference to raw materials and final consumers will have a major impact on the cost of the final product.
    - Capital expenses typically include, but are not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment process.
    - Operating expenses should be calculated as $/m3 of product produced, or other units, as appropriate) on an annual basis for the full-scale plant including, but not limited to, materials needed, including consumables (chemicals, sacrificial components, etc.) In addition to other operating costs that your team identifies, include these operating costs: staff labor rate of $70/hour; solids disposal costs ($50/ton); energy requirements (cost/bbl and Kwh/bbl): research an industrial natural gas rate and state in $/MM BTU; use an electricity rate of $0.09/kWh.
    - Visualization tools: Sensitivity analyses, etc. (Recommended: NMSU TEA Short Course).
- Include a Public Involvement Plan, as applicable (See Team Manual).
- Address safety aspects of handling the mine slag, processing equipment, and any final products. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).
- Document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project to qualify for the P2E2 Award. Place this in a separate section of the report.
- Discuss the intangible benefits of the product compared with using mine slag repositories, e.g., higher stability, reduced footprint, salable by-product, less energy input.

Bench Scale Demonstration

Demonstrate the production process using a bench-scale design for the final copper-smelter slag product using actual slag.

In late January, 2022, teams will be shipped up to ten 5-gallon pails of slag from the Freeport-McMoRan site in Miami, Arizona. Amount to be shipped will be justified in the team's preliminary report. Teams are asked to return unused portions of slag to Freeport-McMoRan.

Teams are urged to research the proceesing, composition, and properties of the copper smelting slag from the Miami, Arizona mine prior to developing a plan for their product or process.

Technical Report Requirements

The written report should demonstrate your team's insight into the full scope of the issue and include all aspects of the problem and your proposed solution. The report will be evaluated for quality of writing, logic, organization, clarity, reason, and coherence. Standards for publications in technical journals apply.

In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, Evaluation Criteria, and 2022 Team Manual.

Evaluation Criteria

Each team is advised to read the 2022 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in this manual, your response to this Task consists of four parts: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, and a poster that conveys the essence of your work in a concise fashion using a mix of text and graphics. General criteria used by the judges in evaluation of these four components are described in the Team Manual.

In the context of the above, your response to the problem statement will include consideration of the following points specific to this task.

- Potential for real-life implementation, including cost, expected reliability, and maintainability. Judges will weigh the cost/benefit of your solution against those for other teams.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The quality of your treated sample. The bench-scale processed water will be evaluated for treated water volume and separation efficiency.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs).

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

References

[1] Fan, Y.; Zhang B.; Song, J.; et al. An Innovated Application of Reutilize Copper Smelter Slag for Cement-based Electromagnetic Interference Composites. Sci Rep 8, 16155 (2018).

[2] Wang, J-P and U Erdenebold. A Study on Reduction of Copper Smelting Slag by Carbon for Recycling into Metal Values and Cement Raw Material. Sustainability 2020, 12, 1421

[3] Freeport-McMoRan, North America, Miami, AZ. https://www.fcx.com/operations/north-america (Accessed 8/6/2021)

[4] Jones, David M. ; Brandt, Robert ; Nanda, Avi ; Piatkiewicz, Alex (2019). Environmental Upgrade at the Freeport McMoran Miami Smelter. Proceedings of the 58th Conference of Metallurgists Hosting Copper 2019.

[5] Arizona Department of Environmental Quality, Draft Technical Support Document, Air Quality Permit No. 66039, Freeport McMoRan Miami, Inc. – Smelter. (http://static.azdeq.gov/pn/tsd_freeport.pdf) Accessed 8/6/2021.

FAQs/Deadlines

- Mid-December, 2021 EH&S Short Course (watch website for dates and registration info).
- Early-Mid January: Freeport-McMoRan will ship to your team mining slag from their Miami, AZ mine.
- Mid-January, 2022: EH&S Short Course; TEA Short Course
- 1 February, 2022: Experimental Safety Plan (ESP) due
- 7 February, 2022: Preliminary Report due
- 7 March, 2022: Send a draft of the technical report to your auditors (approx. date–see Team Manual)
- 28 March, 2022: Technical Report due
- Weekly: Teams are expected to check the FAQs online weekly for any updates in the task requirements. (wercdesigncontest.nmsu.edu)

Short Courses
WERC is offering two short courses. The optional courses are designed to prepare teams to more effectively complete their technical report and earn digital badges to add to their professional development portfolio. The courses are also available to the general public to gain professional development. Fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration.

Courses offered:

- Health and Environmental Safety (EH & S) (Mid-December and Mid-January)
- Techno-economic Assessment and Analysis (TEA) (Mid-January)

Awards
The WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes, below.
1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Virtual Desktop Study Awards (awarded independently of the full bench-scale designs. Amounts TBA.
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award (P2E2 Award) ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. ($500-$1000, according to funding).

Additional awards may be announced at a later date.

Award amounts listed are minimum amounts and may increase with available funding. Detailed criteria for each award are listed in the 2021 Team Manual: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/