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Reprocessing of tailing from Erdenet copper ores: Optimization of the chemical reagents for the leaching

Bachelor Thesis

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Terminology

RMPL	Raw Material Process Laboratory
EMC	Erdenet Mine Corporation
LLC	Limited Liability Company
Cu	Copper
Al	Aluminum
Ag	Silver
Au	Gold
ADRIANA facilities	Airborne spectral Detection of Reusable Industry materials in tailings facilities
USGS	United States Geological Survey
GDP	Gross Domestic Product
TSF	Tailing Storage Facilities
EPA	Environmental Protection Agency
XRF	X-Ray Fluorescence
DO meter	Dissolved Oxygen meter

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Abstract

This thesis paper is conducted as an extension of the "Adriana" project, focusing on the exploration of reprocessing possibilities for the tailings generated by the Erdenet copper and molybdenum mining company. The main objective of this study is to investigate the feasibility of employing the mechanical flotation process to recover valuable minerals from the tailings. The decision to undertake this research is motivated by historical data obtained from EMC LLC, which indicates that the copper content in the tailings exceeded 0.1% as a result of past operational activities and the absence of advanced technological approaches. This finding highlights the potential value and significance of implementing an efficient reprocessing strategy to extract valuable resources from the tailings, thereby mitigating waste and enhancing resource utilization in the mining industry.

The reprocessing of the Erdenet copper-molybdenum mine tailing pond has been investigated through leaching experiments using sulfuric acid and glycine as reagents. Sample preparation was performed to ensure representative and homogenized samples. Sulfuric acid leaching experiments revealed a higher effectiveness in dissolving copper ions, demonstrating its well-known efficiency in leaching processes. On the other hand, glycine, a promising commercial reagent with lower toxicity compared to cyanide, exhibited lower copper ion dissolution than sulfuric acid. The addition of hydrogen peroxide proved effective in oxidizing the copper sulfide ore during glycine leaching, although precautions are required to prevent high-pressure incidents. pH adjustment using sodium hydroxide allowed for alkaline conditions in glycine leaching, albeit at a lower pH level than the optimal range. These findings contribute to the development of sustainable reprocessing strategies for mining waste, paving the way for future optimization and resource-efficient practices.

1 Introduction

Copper is a metallic element with the symbol Cu and atomic number 29, atomic mass 63.546. It is also a highly malleable, ductile, and soft metal that is also an excellent conductor of both electricity and heat. It has a reddish-orange color and a face-centered cubic crystalline structure. Copper is a transition metal, which means it has partially filled d-orbitals that give it its unique properties.

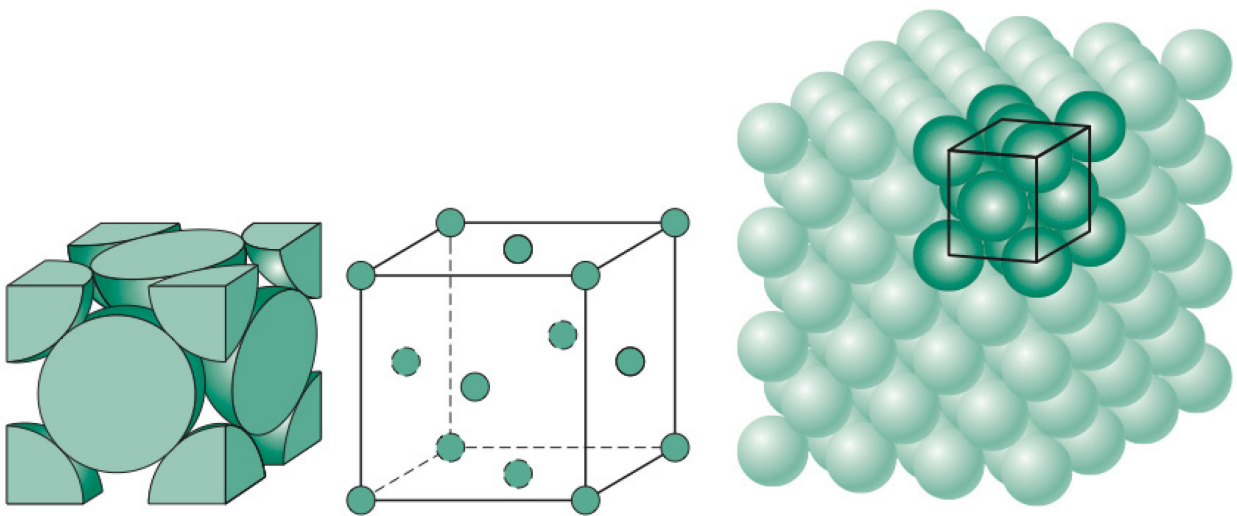


Figure 1. 1 A face-centered cubic crystal of copper

The face-centered cubic crystal structure is a commonly observed arrangement in metallic materials, characterized by atoms situated at each corner of the cube and six atoms at each face of the cube. This structure allows for a maximum theoretical packing density of atoms, making it one of the most tightly packed crystal arrangements known. A visual representation of this structure is shown in the figure below. Notably, several important metals such as Cu, Al, Ag, and Au are known to exhibit the face-centered cubic structure. Its high packing density and resulting high density and conductivity make it an attractive choice for industrial applications.[1]

The electron band structure of copper gives it a distinctive red-orange color, as it reflects red and orange light while absorbing other frequencies in the visible spectrum. This property makes copper a popular material for decorative and ornamental objects, as well as electrical wiring.

Copper has high thermal and electrical conductivity, making it a valuable material in various industries such as electronics, construction, and transportation. Its malleability and ductility make it easy to shape and form into wires, sheets, and other forms. Copper is also highly resistant to corrosion, making it a durable and long-lasting material.

Copper is widely distributed in nature and is found in various ores such as chalcopyrite, bornite, and malachite. It is usually extracted from these ores through a process of smelting, leaching, or electrolysis.

In addition to its industrial uses, copper has been used for centuries in various cultural and artistic contexts. The metal has been used for coinage, sculpture, and architecture, among other things. Today, copper is an important material for sustainable energy applications such as solar panels, wind turbines, and electric vehicles.

This research investigates the possibility of reprocessing of tailing from the Erdenet Copper-Molybdenum mining using a leaching process in different types of chemical reagents.

1.1 General background

The reprocessing of tailing ponds is an effective way to recover the copper resources that may have been lost during the initial processing of the ore. This can help conserve valuable resources and reduce the need for new mining activities. Moreover, reprocessing of tailing ponds can reduce the environmental impact of mining activities by minimizing the amount of waste material that is deposited in tailing ponds.

However, reprocessing of tailing ponds is not without its technical challenges. These challenges include optimizing the leaching process, selecting appropriate reagents, and ensuring efficient copper recovery. Hence, conducting a thesis focused on the technical aspects of copper tailings reprocessing can provide valuable insights into these challenges and potential solutions.

Furthermore, reprocessing tailing ponds can become an economically viable option if the cost of processing is lower than that of mining new copper deposits. Therefore, conducting a thesis focused on the economics of copper tailings reprocessing can provide insights into the viability and profitability of these processes, making it an area of great interest and significance for both the technical and economic aspects of the mining

industry. Reprocessing of tailing ponds may also be subject to regulatory requirements, including environmental regulations and permitting requirements.

In summary, understanding the various aspects of copper tailings reprocessing can provide valuable insights into the potential benefits and challenges of these processes. It is a multidimensional topic that requires a comprehensive understanding of technical, economic, regulatory, and environmental aspects.

1.1.1 Significance of copper

As mentioned above, copper is a versatile and important metal with significant applications in various fields, including industry, technology, construction, and healthcare. One of the key significance of copper is its electrical conductivity, which makes it an essential component in electrical wiring, motors, and other electrical equipment. In addition, copper is also a good conductor of heat, which makes it useful in cooling and heating systems. Furthermore, copper has natural antimicrobial properties, which make it useful in medical settings, such as in the manufacture of medical instruments, hospital surfaces, and even in the treatment of certain conditions. Copper is also highly resistant to corrosion, making it useful in applications where durability is important, such as in plumbing and roofing. The unique color and texture of copper also make it a popular material in interior design, jewelry making, and artistic works. Additionally, copper is used in the production of coins and other currency, due to its durability and resistance to corrosion.

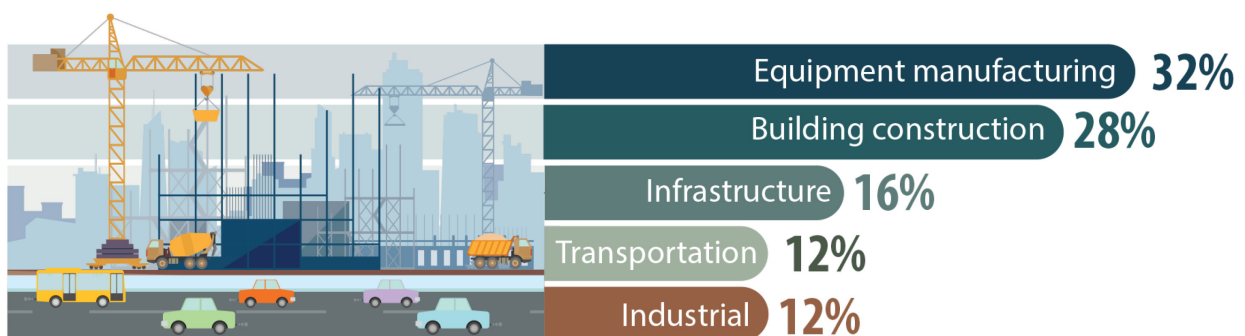


Figure 1. 2 Copper, Global uses in 2020[2]

Copper holds immense significance across diverse industries, including manufacturing and construction, due to its exceptional properties. Furthermore, copper plays a vital role in biological systems as an essential trace dietary mineral. In fact, the adult human body

typically contains between 1.4 and 2.1 milligrams of copper per kilogram of body weight, underscoring its biological importance.

In recent years, the global shift towards green energy has heightened the demand for copper even further. This surge in demand can be attributed to the expanding electricity networks and the widespread adoption of clean energy technologies, such as electric vehicles. Copper's exceptional conductivity and reliability make it a crucial component in these innovative technologies, ensuring efficient power transmission and storage. As the green energy transition gains momentum, the demand for copper is expected to witness a substantial increase, reflecting its pivotal role in enabling a sustainable and clean energy future.

While copper is a valuable resource, its production can have adverse effects on the environment, particularly when waste materials are stored in tailings ponds. Tailings ponds can contain high levels of pollutants, including heavy metals, which can contaminate soil and water sources. These pollutants can have severe impacts on the surrounding ecosystem, including harm to aquatic life and disruption of local plant and animal populations. Additionally, the construction and maintenance of tailings ponds can have further impacts on the environment, such as land use changes, soil erosion, and deforestation. Therefore, it is essential to consider the potential environmental impacts of copper production and implement measures to minimize these impacts.

1.1.2 Copper ore reserve

Copper ore reserves refer to the estimated amount of copper that can be economically extracted from the Earth's crust using current mining technology and at current market prices. The size and location of copper ore reserves are important indicators of the future supply of copper and the potential for new mining activities.

In 2020, Chile boasted the largest copper reserves globally, accounting for approximately 200 million tons, which represents around 23% of the world's total copper reserves. The global copper reserves are estimated to be approximately 880 million tons. In comparison, Canada's copper reserves are estimated at 9.8 million tons, constituting around 1% of the global total. These figures underscore the significant role that Chile plays in the global

copper market, with its substantial reserves serving as a key resource for meeting global demand. Meanwhile, Canada's reserves, although smaller in scale, still contribute to the overall copper supply, highlighting the country's potential as a copper-producing nation[2].

According to the United States Geological Survey (USGS), the world's copper reserves were estimated to be approximately 870 million metric tons in 2020, with the largest reserves located in Chile, Peru, Australia, and the United States. However, the actual amount of copper reserves can vary depending on a range of factors, including changes in mining technology, the discovery of new deposits, and fluctuations in copper prices[3].

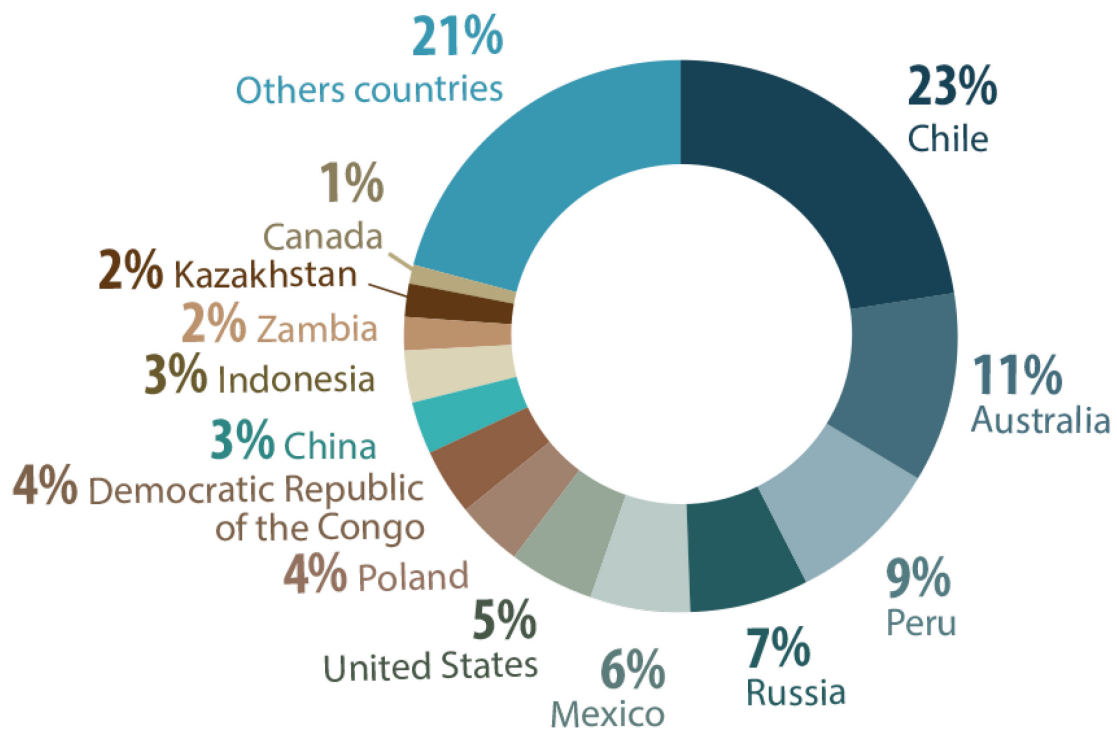


Figure 1. 3 World reserves of copper, by country, 2021[2]

Ranking	Country	Thousand tons	Percentage
1	Chile	5600	26.8%
2	Peru	2200	10.5%
3	China	1800	8.6%
4	Dem.Rep.Congo	1800	8.6%
5	United States	1200	5.7%
6	Australia	900	4.0%
7	Zambia	830	3.9%
8	Russia	820	3.9%
9	Indonesia	810	3.9%
10	Mexico	720	3.4%
11	Canada	542	2.6%
	Other countries	3710	17.7%
Total		21000	100%

Table 1. 1 World mine production of Copper, by Country 2021[2]

In 2021, Chile maintained its prominent position as the leading global producer of mined copper, accounting for 5.6 million tons, which represents 28% of the total global mined copper production. This significant output solidified Chile's status as a key player in the copper mining industry. On a global scale, the total mined copper production reached approximately 21 million tons in 2021, highlighting the substantial contribution of Chile to the overall supply.

Chile has been a major copper producer for several decades and is home to some of the world's largest copper mines. The country's copper reserves are located mainly in the Andes Mountains, where copper deposits are associated with porphyry copper systems. Chile's copper industry is a significant contributor to the country's economy, accounting for a large share of its exports and gross domestic product (GDP)[3].

In terms of refined copper production, the worldwide output saw a modest increase of 1% from 24.5 million tons in 2020 to 24.9 million tons in 2021. The refined copper production includes both primary sources, amounting to 20.8 million tons, and secondary sources, comprising 4.1 million tons. This growth signifies the sustained demand for refined copper and the efforts made to meet global market needs.

It is important to note that copper ore reserves do not necessarily reflect the actual amount of copper that can be mined in the future, as the mining industry must also consider factors such as mining costs, environmental impact, and social considerations. Moreover, the actual amount of copper reserves can vary depending on a range of factors, including changes in mining technology, the discovery of new deposits, and fluctuations in copper prices.

Additionally, the demand for copper can vary over time, influenced by economic factors such as global trade, and technological advances, and political factors such as changes in regulations and policies.

Mongolia also has significant copper reserves, although they are not as large as those of Chile. According to the USGS, Mongolia had an estimated 28 million metric tons of copper reserves as of 2020, which represents about 3% of the world's total copper reserves[3].

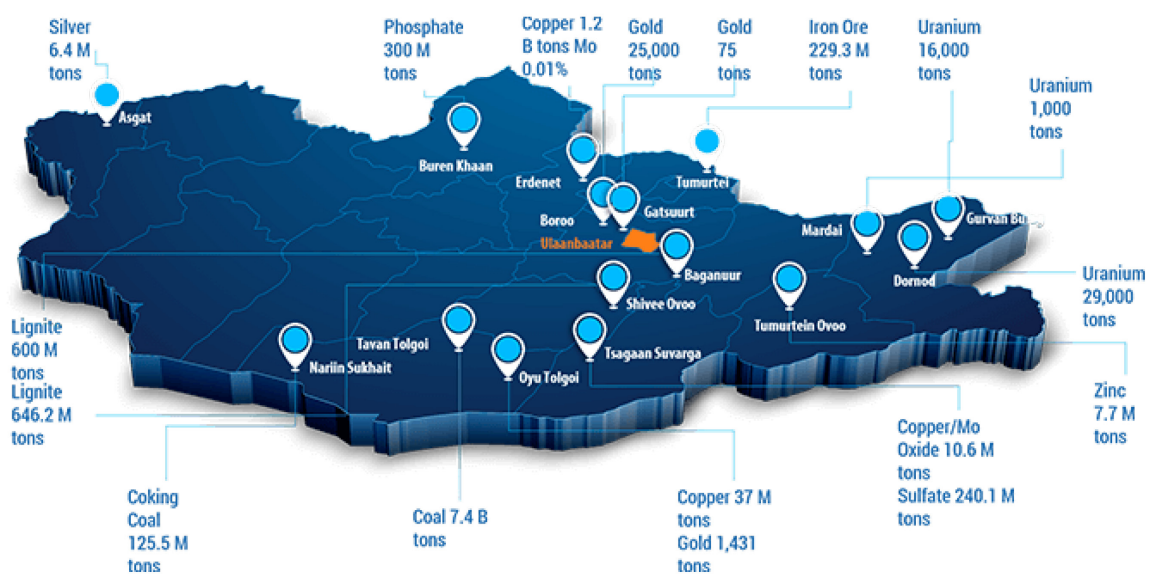


Figure 1. 4 Mongolian mineral reserves

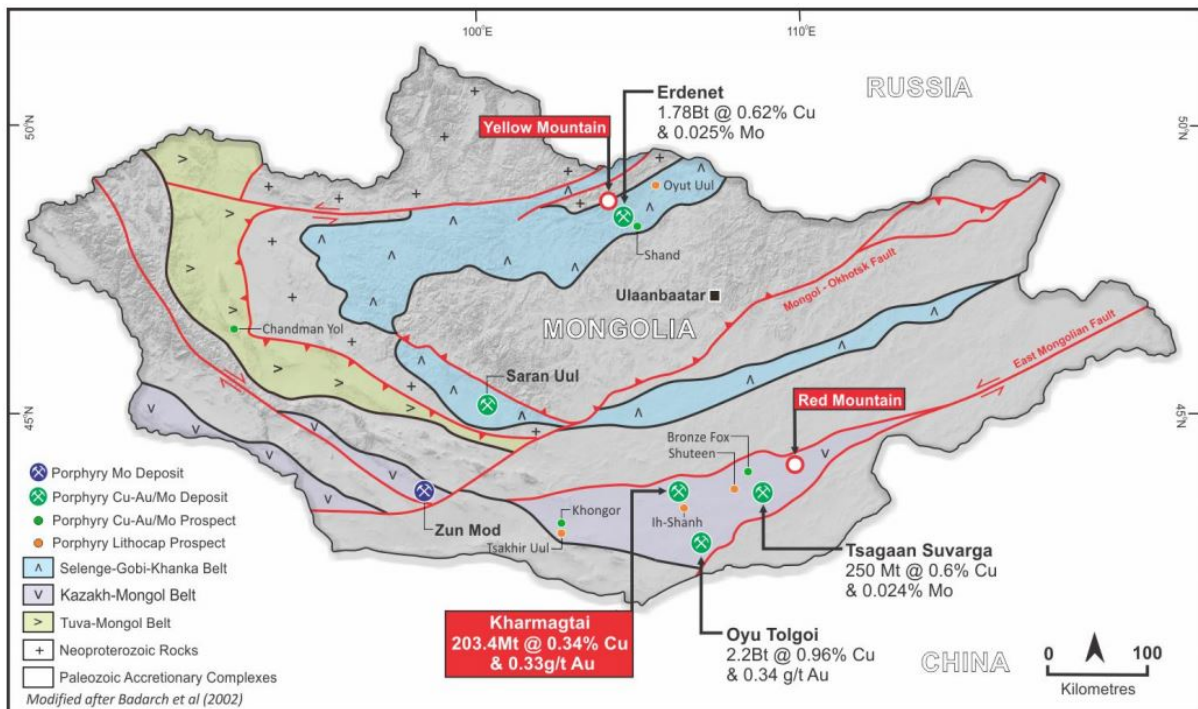


Figure 1. 5 Mongolian main Copper Reserves

The main copper deposits in Mongolia are located in the South Gobi region, where large-scale mining operations are underway. The Oyu Tolgoi mine, operated by Rio Tinto, is one of the largest copper-gold deposits in the world and is a significant contributor to Mongolia's economy.

The Erdenet Copper-Molybdenum Mine is one of the largest and most important mining operations in the country. It is a joint venture between the Mongolian government and the Russian mining company Rostec. The mine has been in operation since 1978 and has played a significant role in the development of Mongolia's mining sector[4].

In summary, copper ore reserves are estimates of the amount of copper that can be extracted from the Earth's crust using current mining technology and at current market prices. Understanding the size and location of these reserves is important for predicting future copper supply and potential new mining activities. Mongolia has significant copper reserves, particularly in the South Gobi region, but they are not as large as those of some other copper-producing countries such as Chile. Despite the challenges facing the industry, Mongolia's copper industry has the potential for significant growth in the future, driven by the development of new mines and the expansion of existing operations.

1.2 Problem Statement and Hypothesis

Raw resources, including mineral resources, are vital for the functioning of modern society. They must be accessible and affordable to support economic activity. The increasing demand for minerals suggests that there is a need for additional supply. One strategy that is both economically and environmentally efficient is to upgrade processing plant output by reusing industrial waste. Mining operations produce significant amounts of mining waste that may contain uncovered valuable minerals, which can be economically recovered. To address the insufficiency of mineral resources, researchers are studying the potential for decreasing and enriching mining waste. Therefore, reusing, reprocessing, and reducing mine wastes can have a substantial impact on the sustainability of the development and creation of environmentally friendly mines. The graph which is shown below shows the demand for copper[5].

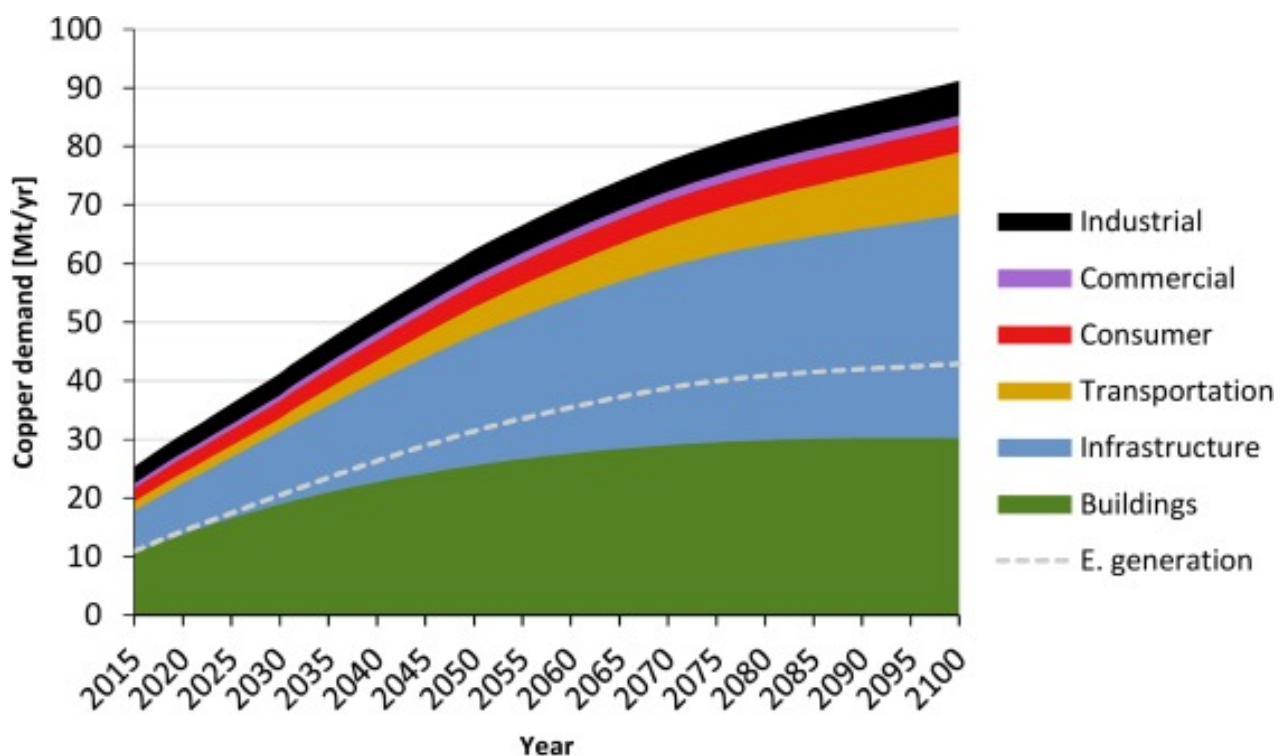


Figure 1. 6 Global copper demand until 2100 with regression and stock dynamics

One of the largest sources of mineral resources is the tailing pond of the Erdenet mine, which has been operating for 44 years. The tailing pond covers a total area of 18.6 square kilometers as of January 2015, with a designed capacity of 1700 million cubic meters and an embankment level of 1320 meters. However, the embankment level had already reached

1300 meters seven years ago, and the mine upgraded production by 6 million tons per year in 2019. The mining company now faces the challenge of dealing with a mine closure plan for old mine tailing ponds and designing a new one. The current TSF has a problem with an increasing pond level of about 1.8 meters each year. As a result, there is a need for solutions to handle this problem to ensure the sustainability of the mineral resource supply from the Erdenet mine.

Hypotheses:

- The application of leaching to the recycling of mine tailings is a viable method for extracting valuable minerals from tailings.
- Leaching of tailings ponds using glycine would be more effective than using sulfuric acid.
- Lower the glycine concentration, higher the copper recovery.

1.3 Aim and Objectives

The tailing pond of the Erdenet copper-molybdenum mining site currently occupies a solid volume of 718 million cubic meters. This study focuses on investigating the effects of additional reagents and their dosages on the leaching process in the special case of the TSF at the Erdenet copper-molybdenum mine. Leaching tests will be conducted to determine the optimal reagent and its dosages that can improve the extraction efficiency of copper from the tailings.

The study aims to explore the potential of using additional reagents to enhance the leaching process and reduce the volume of tailings in the pond. By optimizing the leaching process, the mining operation could improve its resource utilization, reduce waste generation, and minimize the environmental impact of the tailings pond.

Objectives of the study:

- Effect of the different reagents concentrates;
- Compare these reagents with each other to determine which is more effective;
- To optimize additional reagents in the leaching and their dosage at maximum recovery and copper content in the final concentrate;
- To evaluate the performance of the leaching with optimized reagents;

2 Literature review

2.1 Erdenet Copper-Molybdenum Mining

The Erdenet Copper-Molybdenum Mine is one of the largest and most important mining operations in the country. It is a joint venture between the Mongolian government and the Russian mining company Rostec. The mine has been in operation since 1978 and has played a significant role in the development of Mongolia's mining sector.

The Erdenet copper mine is one of the largest copper deposits in the world, with over 1 billion tons of reserves. However, the mining and processing of copper ore generate large amounts of waste in the form of tailings, which can be an environmental and economic liability. In this context, the reprocessing of copper tailings using a leaching process with sulfuric acid and glycine has emerged as a promising approach for recovering copper and other valuable metals in the waste.

Erdenet Copper-Molybdenum mining is considered one of the largest and most significant mining and ore processing facilities in Asia. The Erdenet mine is operated by the Erdenet Mining Corporation LLC, a Mongolian state-owned enterprise. The Mongolian government holds a 51% stake in the company, while Rostec holds the remaining 49% stake. It holds a vital position in the economy of Mongolia, contributing over 20% to the country's economy. The mine is situated in Erdenet City, located in the Orkhon province of Mongolia, in the central part of the country.[5]

The mine has a large-scale open-pit mining operation, extracting copper and molybdenum ores from the ground. The extracted ore is processed through a flotation plant to produce copper and molybdenum concentrates.



Figure 2. 1 Location of the Erdenet city with Erdenet Copper-Molybdenum mine



Figure 2. 2 Location of the Erdenet Copper-Molybdenum mine tailing pond

The main reserve of copper-molybdenum mining at Erdenet is known as Erdenetiin Ovoo. The mine has been operational for several decades and has consistently produced high-quality copper and molybdenum concentrates, making it a valuable asset for the Mongolian mining industry.

Based on the updated reserve estimates from 2016, the "Northwest" deposit in the Erdenet Copper-Molybdenum mine has a geological reserve of 1,823,953.80 thousand tons, with an average copper content of 0.382% and an average molybdenum content of 0.015%. The mineable reserve is 1,108,393.2 thousand tons, with an average copper content of 0.044% and an average molybdenum content of 0.019%. As per the 2013 estimations, the "Central" section of the mine has a reserve of 201,472.63 thousand tons of ore with an average copper content of 0.410% and an average molybdenum content of 0.173%. The Erdenet mine deposit has three types of copper ore, namely, oxidized ore, secondary ore, and primary ore.

Currently, EMC operates a complex plant with a processing capacity of approximately 32 million tons of ore per annum. The plant produces around 569,000 tons of copper concentrate annually, containing 23-25% copper, less than 0.15% molybdenum, and 23-28% iron, as well as around 4.7 thousand tons of molybdenum concentrates annually. The molybdenum concentrate has a grade of 48-50% molybdenum, less than 4% copper, and around 3.5 to 6% silicon dioxide.

2.2 Mine waste/ Mongolia and other countries/

Mining operations generate a wide range of waste streams, the majority of which are waste rock and tailings. However, the amount of mine waste produced can vary depending on various factors such as the type of mineral being extracted, the size of the mine, and the mining method used. In the case of typical copper mines, the amount of mine waste generated can be up to 450 times greater than the total mined product. It is important to manage and dispose of mine waste appropriately to minimize the environmental impact and potential harm to surrounding communities.

Mining operations generate various waste streams, with waste rock and tailings being the most significant in terms of quantity and importance. These waste streams can have a considerable impact on the total waste output of the country where the mining takes place.

For instance, in the case of copper mining, it is estimated that 400 tons of waste rock are produced for every ton of product, while the concentrator generates about 100 tons of tailings per ton of product. However, the actual amount of waste generated is dependent on several factors, including the type of mineral extracted, the size and type of the mine, and the stripping ratio.

Mine waste refers to the materials that are left over after the extraction of minerals from a mine. These materials can include waste rock, tailings, and other byproducts that are generated during the mining process. The management of mine waste is a critical environmental and economic issue, as improper disposal or handling of these materials can have significant impacts on the environment and local communities.

Mongolia is a country that is particularly affected by mine waste. The country has a rich mineral resource base, and the mining industry is a major contributor to the country's economy. However, many of the mining operations in Mongolia generate significant amounts of waste that can have negative environmental impacts. For example, the Erdenet mine, which is one of the largest copper mines in the world and has been in operation for over 40 years, generates massive amounts of tailings that are stored in large tailing ponds. These ponds can leak or overflow, contaminating nearby water sources and posing a threat to local communities.

Other countries also face significant challenges related to mine waste. In South Africa, for example, the Witwatersrand Basin has been the site of extensive gold mining activity for over a century, resulting in large amounts of mine waste that are stored in massive tailings dams. These dams can pose a significant risk of collapse, which can result in the release of toxic waste materials into nearby water sources.

In the United States, the cleanup of mine waste has become a major issue in recent years. The abandoned mines scattered throughout the western US have left behind significant amounts of waste materials that can pose a threat to nearby communities and ecosystems. The Environmental Protection Agency (EPA) has designated over 40 Superfund sites related to mine waste, indicating that the cleanup of these sites will require significant resources and effort.

In the main, the management of mine waste is a critical issue that affects many countries around the world. Strategies such as reusing and recycling waste materials, as well as

improving the design and construction of tailings dams, can help to mitigate the environmental and economic impacts of mine waste.

2.3 Previous approaches to reusing mine tailings

In previous studies and approaches, various methods have been explored for the reprocessing of Erdenet copper-molybdenum tailing ponds. These approaches aimed to recover valuable minerals and mitigate the environmental impact of mining activities.

One common approach is the use of flotation techniques. Flotation involves the separation of minerals from the tailings based on their hydrophobic or hydrophilic properties. This process utilizes chemicals known as collectors, which selectively attach to the desired minerals and promote their flotation. The recovered minerals can then be further processed for metal extraction.

Another approach is leaching, which involves the dissolution of metals from the tailings using chemical reagents. Leaching can be conducted through various methods, including acid leaching and bioleaching. Acid leaching utilizes acidic solutions to extract metals, while bioleaching employs microorganisms to facilitate metal dissolution. These methods have shown promise in recovering copper and other valuable metals from the tailings.

Furthermore, physical separation techniques, such as gravity separation and magnetic separation, have been employed to separate minerals based on their density or magnetic properties. These methods can effectively concentrate valuable minerals and improve the overall recovery rate.

In addition to these conventional approaches, innovative technologies have been explored for tailing pond reprocessing. These include hydrometallurgical processes, such as solvent extraction and electrowinning, which offer efficient ways to extract metals from the tailings. Moreover, advancements in nanotechnology and biotechnology have opened up new possibilities for tailings reprocessing, including the use of nanoparticles and bioleaching agents.

It is worth noting that each approach for the reprocessing of Erdenet copper-molybdenum tailing ponds carries its own set of advantages and limitations. The selection of the most suitable method depends on several factors, including the specific mineral composition of

the tailings, economic viability, and environmental considerations. It is also important to recognize that integrating multiple techniques within a comprehensive reprocessing strategy can significantly enhance the overall efficiency and sustainability of the process.

The previous approaches undertaken for the reprocessing of Erdenet copper-molybdenum tailing ponds have encompassed a diverse range of methods, spanning from conventional techniques such as flotation and leaching to more advanced technologies like hydrometallurgy and nanotechnology. These studies have yielded valuable insights into the recovery of valuable minerals and the utilization of mining waste. By exploring these approaches, researchers and industry professionals have made significant strides towards the development of more sustainable and resource-efficient mining practices. The findings from these studies provide a solid foundation for further research and innovation in tailings reprocessing, with the ultimate aim of minimizing environmental impact and maximizing the recovery of valuable resources.

2.4 Leaching process

The leaching of copper tailings involves the dissolution of copper and other metals from the tailings into a solution, followed by the separation and recovery of the metals. Sulfuric acid is a common leaching agent used for copper recovery due to its strong oxidizing power and low cost. Glycine is an amino acid that has also been used as a leaching agent for copper and other metals, with the advantage of being non-toxic and biodegradable.

Several studies have investigated the leaching of copper tailings using sulfuric acid and glycine. For example, Wei et al. (2018) studied the leaching of copper from tailings using a combination of sulfuric acid and hydrogen peroxide, achieving a copper recovery of over 90%. Hu et al. (2020) investigated the leaching of copper and zinc from tailings using a glycine-based leaching solution, achieving a copper recovery of up to 80%. Zhang et al. (2019) compared the leaching performance of sulfuric acid and glycine for copper recovery from tailings and found that glycine was more effective at lower concentrations.

In the case of the Erdenet tailing pond, several studies have reported on the potential for recovering copper and other metals using a leaching process. For example, Enkhbayar et al. (2019) investigated the leaching of copper and molybdenum from the Erdenet tailings using sulfuric acid and found that recovery of up to 92% was possible. Batnasan et al. (2021) also

investigated the use of glycine for copper recovery from the Erdenet tailings, achieving a copper recovery of up to 80%.

The reprocessing of the Erdenet tailing pond using a leaching process with sulfuric acid and glycine has the potential to recover significant amounts of copper and other valuable metals. Previous research has demonstrated the effectiveness of these leaching agents for copper recovery from tailings, and specific studies have shown promising results for the Erdenet tailings. However, further research is needed to optimize the leaching process and to evaluate the environmental and economic feasibility of this approach.

2.4.1 Parameters for Leaching

Leaching is a common method used in the mining industry to extract valuable metals from ores. The effectiveness of leaching is determined by several factors, including the leaching reagent used, the particle size of the ore, the temperature and pressure of the leaching process, and the duration of the leaching process. Other important parameters include the concentration of the leaching solution, the stirring speed, and the pH of the solution.

The selection of the appropriate leaching reagent depends on the specific mineral being extracted and the desired final product. For instance, sulfuric acid is often used for the leaching of copper ores, while cyanide is commonly used for gold extraction.

The particle size of the ore is another important factor, as it influences the surface area available for leaching. In general, finer particles tend to have a higher leaching rate. The temperature and pressure of the leaching process can also impact the effectiveness of leaching. Increasing the temperature can accelerate the leaching reaction while increasing pressure can increase the solubility of the target metal. The duration of the leaching process depends on the desired extraction rate and the specific mineral being extracted.

Finally, the concentration of the leaching solution, the stirring speed, and the pH of the solution can also affect the rate and efficiency of the leaching process. Overall, understanding and optimizing these parameters is crucial for the successful implementation of leaching as a mineral extraction method.

2.4.2 Reagents for Leaching

Reagents are vital in the leaching process as they facilitate the dissolution of metals from the ore. The selection of appropriate reagents depends on a number of factors, including the type of ore being processed, the desired metal to be extracted, and the specific leaching conditions. The choice of reagent can significantly affect the efficiency and selectivity of the leaching process, as well as its environmental impact.

Acids, such as sulfuric acid and hydrochloric acid, are commonly used in acidic leaching. Sulfuric acid is particularly effective in extracting copper and gold from ores due to its strong oxidizing properties. However, it is important to carefully control the concentration and temperature of the acid to prevent unwanted side reactions, such as the formation of sulfur dioxide gas. Other reagents, such as nitric acid and ammonium sulfate, are also used in acidic leaching processes.

In alkaline and cyanide leaching, reagents such as ammonia, sodium cyanide, and thiosulfate are commonly used. Sodium cyanide is particularly effective in extracting gold from ores due to its strong complexing ability with the metal. However, the use of cyanide is controversial due to its toxicity and environmental concerns. Alternative reagents such as glycine and thiosulfate have been investigated as potential replacements for cyanide in gold leaching. In recent years, alternative reagents such as glycine and thiosulfate have been investigated for their potential to replace cyanide in gold leaching. These reagents may also be used in combination with other additives to improve the leaching efficiency or to suppress unwanted reactions.

In addition to acids and alkalis, chelating agents such as EDTA (ethylenediaminetetraacetic acid) and DTPA (diethylenetriaminepentaacetic acid) are also used in leaching processes to enhance metal solubility. These chelating agents form stable complexes with metal ions, preventing them from precipitating out of the solution.

In the last, the selection of appropriate reagents for the leaching process is crucial in achieving high metal extraction rates and minimizing environmental impacts. Careful consideration must be given to the choice of reagent, as well as its concentration, temperature, and potential for interfering reactions. The choice of reagent also affects the kinetics and efficiency of the leaching process.

3 Methodology

The methodology employed in this study was based on an experimental qualitative design. The research procedures encompassed various stages, including sample preparation, sample analysis, leaching, slurry filtration, and sample drying, all of which were conducted in the Raw Material Process Laboratory (RMPL). The RMPL served as the central facility for executing these essential tasks, ensuring standardized and controlled conditions throughout the experimental process.

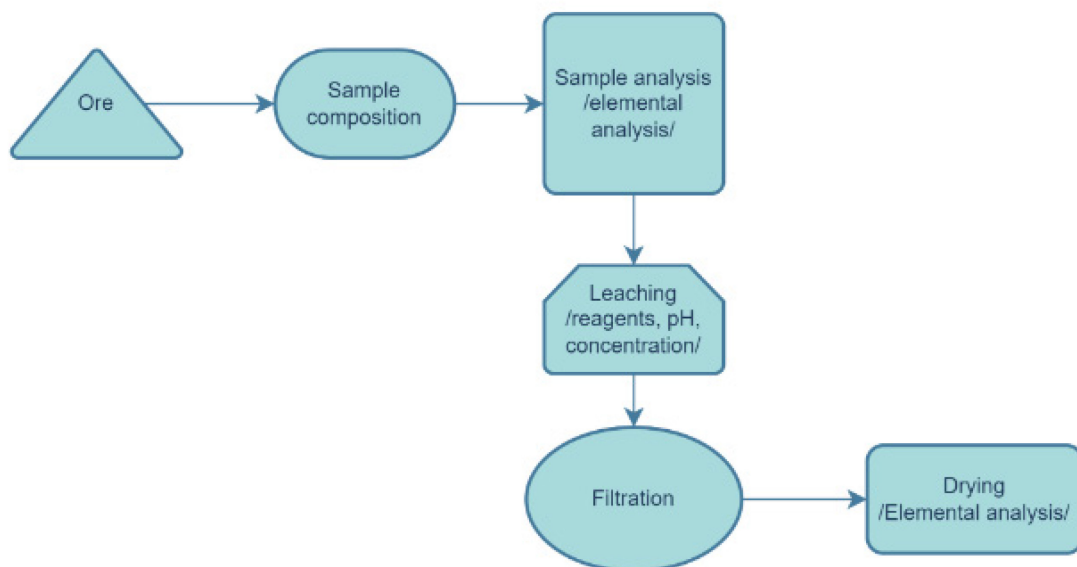


Figure 3. 1 General overview of the Methodology section

3.1 Apparatus and Equipment

This section includes detailed information on the main apparatus and equipment used during the testing process. Moreover, it consists of a comprehensive description of the equipment, including its technical specifications, its purpose in the testing process, and how it was utilized. Additionally, it also describes any adjustments made to the equipment, as well as any safety precautions that were taken during the testing process.

Splitter:

The Retsch sample splitter RT 6.5 is a laboratory instrument that is commonly used for dividing granular materials into smaller samples. This device is designed to provide precise and accurate results while minimizing the risk of contamination between samples.

The device has six slots, each of which can hold a container with a maximum diameter of 64 mm. The slots are adjustable, allowing the user to customize the size of the divided samples according to their specific needs. The process is quick and efficient, allowing for a large number of samples to be prepared in a relatively short amount of time.

The RT 6.5 is a valuable tool for researchers who need to prepare multiple samples for analysis, such as in the case of the leaching test in the reprocessing of copper mine tailings. By using this device, the researchers can ensure that each sample is representative of the original sample, minimizing errors and producing reliable results. Prepared samples are split until 0.45 kg to get ready for upcoming tests.

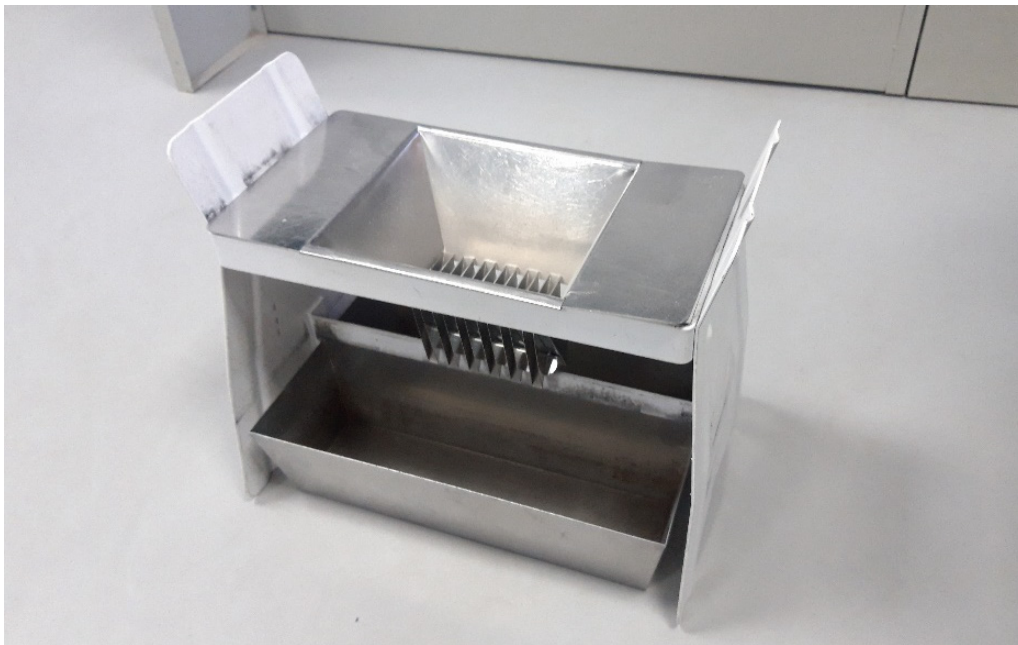


Figure 3. 2 The Retsch sample splitter RT 6.5

Bottle roller:



Figure 3. 3 Bottle roller

Filter:

Mascalab filter presses are extensively used in mining and metallurgical laboratories to separate water from slurries. These filter presses are designed to carry out a variety of tasks, including dewatering, clarification, and filtration. In laboratory experiments, the concentrate and tailings obtained from the leaching tests are poured into a stainless-steel vessel. The vessel is then sealed using a lid, and the air is applied with 600kPa pressure to separate solids from liquids. This process results in the formation of a filter cake that contains the solids, while the water is separated and drained through the filter media. These filter presses are designed to be efficient, reliable, and cost-effective and can be used to process a wide range of mining and metallurgical samples.



Figure 3. 4 Maschalab filter

Drying oven:

The drying oven is a highly versatile piece of equipment commonly used in laboratories for the quick and efficient drying of various materials. With a digital display, the oven allows for precise temperature control within a range of +10°C to 250°C, making it suitable for drying heat-sensitive, easily decomposable, and oxidized materials.

Once the materials are filtered, they can be placed inside the oven where hot air is blown through the chamber by an electric fan, allowing for rapid and even drying. The oven ensures that the materials are completely dried, which is essential in many laboratory experiments and procedures where moisture content can affect the accuracy and reliability of the results. The drying oven is an essential piece of equipment in many laboratory settings, enabling researchers to carry out experiments and procedures more efficiently and with greater accuracy.



Figure 3. 5 Drying Oven

XRF:

The XRF (X-Ray fluorescence spectroscopy) analyzer is a highly useful and widely used tool in the mining and exploration industries. XRF analyzers are analytical instruments used to determine the elemental composition of materials. They work by irradiating a sample with X-rays, which cause the atoms in the sample to emit fluorescent X-rays that can be measured and analyzed. It allows for the quick and non-destructive verification of the metal content in a range of 30 elements, as well as tramp and trace elements. This handheld analyzer is particularly effective for the primary identification of metal.

The XRF analyzer's accuracy, however, can be influenced by the particle size of the sample being analyzed. Therefore, particle size distribution analysis is an important consideration when using the XRF analyzer.

One of the significant applications of the XRF analyzer in mining and metallurgy is the determination of the copper content in concentrate and tailing samples of the leaching process. The XRF analyzer provides an efficient way to determine the copper content in these samples, which is essential for quality control and process optimization. By analyzing the copper content in the concentrate and tailing samples, the efficiency of the leaching process can be assessed, and any necessary adjustments can be made to ensure optimal copper recovery. The XRF analyzer is an essential tool in mining and metallurgical laboratories, enabling efficient and accurate analysis of the metal content in a range of samples.



Figure 3. 6 XRF analyzer

pH meter:

The pH meter is an essential instrument used in many scientific fields, including mining and metallurgy. The meter has an impressive accuracy of 0.05 pH and comes with two-point calibration. It is designed to work in a wide temperature range of 0 to 100°C and can measure pH values in the range of 0.00 to 14.00 pH. This makes it an ideal tool for laboratory purposes, where precise pH measurements are crucial for chemical experiments

and quality control. In the leaching process, the pH of the slurry is an important parameter that needs to be carefully monitored and controlled to ensure optimal extraction efficiency.

It is a portable and easy-to-use instrument that can be used to measure the pH of slurry samples in plastic bottles. The meter can also be used to adjust the pH of the slurry by adding acid or base solutions, as required. The meter is designed to measure pH and temperature simultaneously, providing accurate and reliable readings in a compact and easy-to-use package.

In the context of reprocessing copper mine tailings, pH measurements are crucial for ensuring that the leaching process is efficient and effective.



Figure 3. 7 pH meter

DO meter:

The DO meter used in those experiments is ProODO Handheld Optical Dissolved Oxygen Meter. Dissolved oxygen is one of the parameters which is measured during the experiment. The ProODO Handheld Optical Dissolved Oxygen (DO) Meter is a portable, handheld device designed to measure dissolved oxygen in water using an optical sensor. The meter is

commonly used in applications such as wastewater treatment, aquaculture, and environmental monitoring.

In the context of reprocessing copper mine tailings, dissolved oxygen measurements can be used to monitor the progress of the leaching process. As the leaching solution reacts with the copper in the tailings, dissolved oxygen levels will change. By using a meter like the ProODO Handheld Optical DO Meter, researchers can monitor these changes and adjust the process as needed to optimize copper recovery.



Figure 3. 8 ProODO Handheld Optical Dissolved Meter

3.2 Solution preparation:/chemical reagents/

During the testing phase, two different types of solutions were prepared for use in the leaching process. These solutions differed in their concentrations of sulfuric acid and the concentration of glycine. The varying concentrations of these key components allowed for systematic investigation and comparison of their effects on the leaching process.

Additionally, different percentages of hydrogen peroxide were used in conjunction with the glycine to help oxidize the copper sulfide ore and facilitate the leaching process. Different proportions of hydrogen peroxide were incorporated to aid in the oxidation of the copper sulfide ore, thereby promoting the leaching process. This oxidative action facilitated the breakdown of the ore particles, enhancing the extraction of copper from the ore matrix.

The concentration of sulfuric acid in the solutions was varied to investigate the effect of acid concentration on the leaching efficiency. Similarly, varying amounts of glycine were added to the solutions to determine the optimal concentration of glycine needed to maximize copper recovery. The percentage of hydrogen peroxide added was varied to determine the optimal amount needed to achieve efficient oxidation of the ore and subsequent copper recovery.

By varying these parameters, careful monitoring of the leaching process can determine the optimal conditions required for efficient copper extraction from waste.

As mentioned before, two distinct solutions were prepared for the leaching process. These solutions differed in their composition, with one containing sulfuric acid and the other incorporating glycine as a key component. However, the use of glycine necessitated the addition of an auxiliary chemical agent to regulate the pH levels effectively. In this case, sodium hydroxide was employed as a pH controller during the experiments. By carefully adjusting the pH using sodium hydroxide, the researchers aimed to optimize the leaching conditions and enhance the overall efficiency of the process. This strategic approach ensured the appropriate conditions for the successful extraction of copper from the ore samples.

To maintain a solid-liquid ratio of 3:7, a total of 1050 grams of solution was required for the experiment. The preparation process involved creating a concentrated solution with a specific composition, which is outlined in the table provided. The table details the concentration of sulfuric acid used in the preparation. Additionally, to form the slurry, 450 grams of solid particles were added to the solution. This meticulous procedure ensured the desired consistency and composition of the slurry, setting the foundation for accurate and reliable experimental results.

H ₂ SO ₄ , M	H ₂ SO ₄ , ml	Solid, g	Water, g
0.05M	2.946	450	1050
0.1M	5.892	450	1050

0.3M	17.675	450	1050
0.5M	29.46	450	1050

Table 3. 1 Sulfuric acid solution preparation

As previously mentioned, as part of the experimental procedure, a glycine solution weighing 1050 grams was prepared to maintain the desired solid-liquid ratio. Following the preparation of the solution, 450 grams of solid particles were carefully introduced into the solution. Subsequently, sodium hydroxide, serving as the pH-controlling agent, was added to the solution until the pH level reached 10. This precise adjustment of the pH ensured optimal conditions for the subsequent leaching process. With all the necessary preparations completed, the leaching process was initiated, allowing for the desired chemical reactions to occur and the extraction of desired components from the solid particles in the solution.

Glycine, M	Glycine, g	Solid, g	Water, g
0.1	7.88	450	1050
0.3	23.65	450	1050
0.5	39.41	450	1050
0.8	63.06	450	1050

Table 3. 2 Glycine solution preparation

3.3 Experimental method

The experimental work for this thesis was conducted in the raw material process laboratory, which provides a controlled environment for conducting leaching experiments. Several leaching methods were considered for the study, and ultimately, the bottle roll leaching method was chosen as the most suitable approach. This method was selected due to its ease of use, efficiency, and faster turnaround time compared to other available leaching methods. By utilizing the bottle roll leaching method, the experimental process was streamlined, allowing for a more efficient and effective investigation of the reprocessing of the Erdenet tailing pond using sulfuric acid and glycine.

This method involves agitating a solid-liquid mixture in sealed containers, simulating the leaching process on a laboratory scale. In the context of reprocessing the Erdenet tailing pond using sulfuric acid and glycine, the bottle roll leaching method offers several advantages:

The bottle roll method allows for the simulation of leaching conditions similar to larger-scale operations. It provides a representative view of how the leaching agents interact with the tailings, allowing for insights into the potential extraction efficiency. Bottle roll leaching is relatively simple to perform and requires minimal equipment. It involves placing the solid-liquid mixture in a sealed bottle or vessel and subjecting it to controlled agitation. This makes it suitable for laboratory-scale studies and allows for easy replication of experimental conditions.

The bottle roll method allows for periodic sampling of the leaching solution during the experiment. These samples can be analyzed to determine the concentration of dissolved copper and other relevant parameters. By collecting samples at different time intervals, it becomes possible to monitor the leaching progress and evaluate the leaching efficiency over time. Bottle roll leaching offers flexibility in controlling various leaching parameters. Factors such as solid-to-liquid ratio, leaching time, temperature, and pH can be adjusted to mimic specific operational conditions or to optimize the leaching process. This flexibility enables the investigation of different leaching conditions and their impact on copper extraction.

Generally, the bottle roll leaching method is a valuable tool in assessing the leaching behavior of copper sulfide ores or tailings. It provides insights into the performance of leaching agents and helps in optimizing the leaching process. By utilizing this method in your thesis work on the reprocessing of the Erdenet tailing pond using sulfuric acid and glycine, you can gain a comprehensive understanding of the leaching behavior and assess the potential for copper recovery.

3.3.1 Elemental analysis for XRF:

Elemental analysis is a crucial step in reprocessing copper tailing ponds using chemical reagents and leaching. XRF analysis is a commonly used method for elemental analysis in the mining industry. XRF analysis measures the fluorescent X-rays emitted by the sample when it is bombarded with high-energy X-rays. The intensity and energy of the emitted X-rays are characteristic of the elements present in the sample, allowing for the identification and quantification of the elemental composition of the tailings.

XRF analysis is a non-destructive method that can be performed on solid or powdered samples. The advantage of XRF analysis is its speed and ease of use, as it does not require extensive sample preparation or use of hazardous chemicals. XRF analysis is also capable of detecting a wide range of elements, from heavy metals to light elements such as carbon and oxygen.

In the context of reprocessing copper tailing ponds with chemical reagents and leaching, XRF analysis can provide critical information about the elemental composition of the tailings, which is essential for designing an effective reprocessing strategy. The concentration of copper and other valuable elements, as well as potential contaminants, can be determined using XRF analysis. This information can then be used to determine the appropriate chemical reagents and leaching conditions required for copper extraction.

XRF analysis can also be used to monitor the progress of the leaching process and determine when it is complete. The concentration of copper in the leach solution can be measured using XRF analysis, allowing for the calculation of the copper recovery rate. This information can be used to optimize the reprocessing strategy and ensure maximum copper recovery.

Lastly, XRF analysis is an essential tool for reprocessing copper tailing ponds with chemical reagents and leaching. It provides critical information about the elemental composition of the tailings and allows for the optimization of the reprocessing strategy, ultimately leading to higher copper recovery rates and reduced environmental impact.

3.3.2 Sample composition for Leaching test

One of the most crucial aspects of sample preparation for the leaching test is ensuring that the copper content is evenly distributed throughout the sample. To achieve this, the sample is thoroughly mixed until the copper content is equalized, and then it is split into the desired mass. If the sample's mass is greater than the proposed mass, it is split again until the desired amount is obtained. This process helps to minimize any errors that could lead to uneven copper content in the sample.

In the case of the Erdenet mine process plant, the samples were already in the form of fine particles, so there was no need to grind them further. The primary aim of the leaching test

was to optimize the conditions for the reagents, so regrinding was not necessary. However, it was still important to mash the sample well to ensure that all parts of the specimen were fully separated. This was especially important since the samples were taken directly from the tailing pond, and some parts of the specimen were stuck together.

By taking these precautions during sample preparation, the researchers can ensure that the leaching test results are accurate and reliable, which is essential for determining the optimal conditions for reprocessing the copper from the tailings

3.3.3 Leaching test

First of all, the leaching pH is hugely predominant, it can affect the solution's copper extraction ability directly. In that 2 chemical reagents which are sulfuric acid and glycine,

Sulfuric acid is commonly used as a leaching agent in the hydrometallurgical extraction of copper from copper sulfide ores. It plays a crucial role in dissolving copper from the ore, enabling the subsequent recovery of copper ions.

The concentration of sulfuric acid used in the leaching process varies depending on factors such as ore composition, leaching efficiency, and process conditions. Typically, sulfuric acid concentrations ranging from 1% to 10% are employed. pH control is important, with an acidic environment ($\text{pH} < 2$) maintained to optimize copper leaching by maximizing copper ion solubility.

Elevated temperatures are often employed during the leaching process to enhance reaction kinetics and accelerate the dissolution of copper sulfide minerals. The duration of the leaching process depends on factors such as ore characteristics, acid concentration, and desired copper recovery rates.

During leaching, impurities present in the ore, such as iron and other metal sulfides, may also dissolve to some extent. This can lead to the generation of impure solutions, necessitating additional purification steps to obtain a high-purity copper product.

It is important to note that the specific details and parameters of sulfuric acid leaching for copper sulfide ores can vary based on ore composition, process design, and operational considerations. Conducting detailed laboratory testing and process optimization is crucial to

determine the most suitable conditions for efficient copper extraction in the reprocessing of the Erdenet tailing pond using sulfuric acid and glycine.

Glycine is an alternative leaching reagent for copper sulfide ores, offering advantages over cyanide, such as lower toxicity and reduced environmental concerns. Its leaching mechanism involves the formation of copper-glycine complexes, dissolving copper from sulfide minerals. The pH is adjusted to alkaline conditions to enhance solubility. The leaching process is conducted at ambient or slightly elevated temperatures, and glycine concentrations range from 0.1% to 1.0%. Additional additives, like hydrogen peroxide, can be used to improve efficiency. Glycine consumption may require replenishment and recycling methods are being explored. Detailed laboratory testing and process optimization are essential for efficient copper extraction.

The experimental procedure involved the utilization of a plastic bottle with a solid-liquid ratio of 3:7. The solid particles weighed approximately 450g, while 1050g of water was used to create the slurry. The slurry preparation began with the formulation of the solution. To achieve this, 1050g of water was required. For the sulfuric acid solution, 800g of water was initially prepared, followed by the slow addition of an appropriate quantity of sulfuric acid to avoid heat generation. It is crucial to note that water should never be added to the acid directly to prevent sudden explosions. Therefore, the first step involved adding distilled water to a suitable container, such as a beaker or plastic container used for the leaching test. Subsequently, the sulfuric acid was introduced, followed by the addition of an additional 250g of water to reach a total solution weight of 1050g.

The preparation of the glycine solution followed a similar process to that of sulfuric acid. However, there were notable differences. Glycine, known for its lower toxicity, required pH adjustment using sodium hydroxide. It is important to highlight that the pH adjustment was carried out after the slurry had been prepared. Once the solution formulation was complete, 450g of tailing specimen was added to the solution, and thorough mixing of the solution and sample was performed. As previously mentioned, glycine necessitated the inclusion of sodium hydroxide as an additional agent for pH adjustment.

During the experiment, samples were collected at 12-hour intervals using a 50ml measuring beaker. In the sulfuric acid leaching process, pH adjustment was not performed to avoid altering the sulfuric acid concentration, which could potentially affect the accuracy of the experiment. However, in the case of glycine leaching, pH adjustment was conducted after each sample collection by adding sodium hydroxide until the pH reached 10. It is worth

noting that the literature review suggests that pH adjustment does not significantly impact the leaching process. Upon completion of the experiment, the slurry was filtered using a pressure filter, and the resulting residue was dried using a drying oven. These steps ensure the proper handling and preparation of the samples for further analysis.

4 Experimental Results and Discussion

4.1 Element analysis

According to the results, the concentration of sulfuric acid in 0.05 M yielded the highest result initially but subsequently decreased to the lowest value, followed by a slight increase. The following graph depicts the XRF result of the leaching residue, where an expected trend of a decreasing graph should be observed if the experiment was performed correctly. However, the graph shows a sudden drop followed by a slight increase, which may be attributed to the accuracy of XRF. There is a possibility of external factors affecting the results, such as the movement of the table during the XRF analysis, the handling of the samples, or inadequate sample preparation. These factors can contribute to inconsistencies in the XRF results, leading to erroneous conclusions. Therefore, it is crucial to consider these aspects while analyzing the data and interpreting the results. Further investigation and attention to experimental details are necessary to obtain accurate and reliable data.

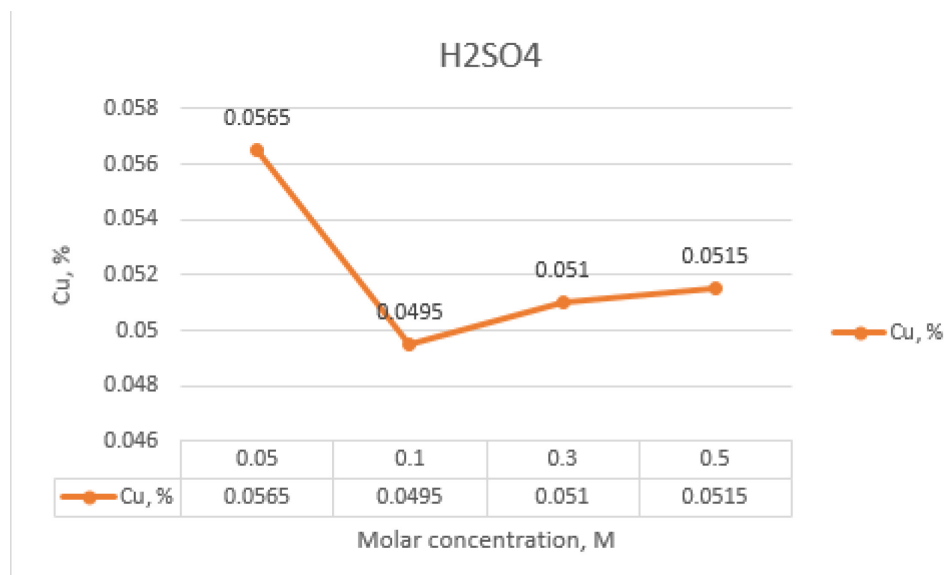


Figure 4. 1 XRF Analyzer Result of Sulfuric acid Residue

The XRF graph below displays the results of the glycine-leaching residue. The decreasing trend observed in the graph suggests that the experiment was performed correctly, and the XRF results are accurate. This trend indicates that as the concentration of glycine increased, more copper ions were dissolved in the solution. The accuracy of the results obtained from the XRF graph can be attributed to the precise measurement and control of the experimental conditions during the bottle roll experiment. The decreasing trend in the graph is an important observation that demonstrates the effectiveness of the glycine leaching method for copper extraction from the ore. The successful application of glycine leaching can help in

reducing the environmental impact of copper mining by minimizing the use of toxic reagents and reducing the production of mining waste. Overall, the results obtained from this experiment hold significant implications for the future of copper mining and its environmental sustainability.

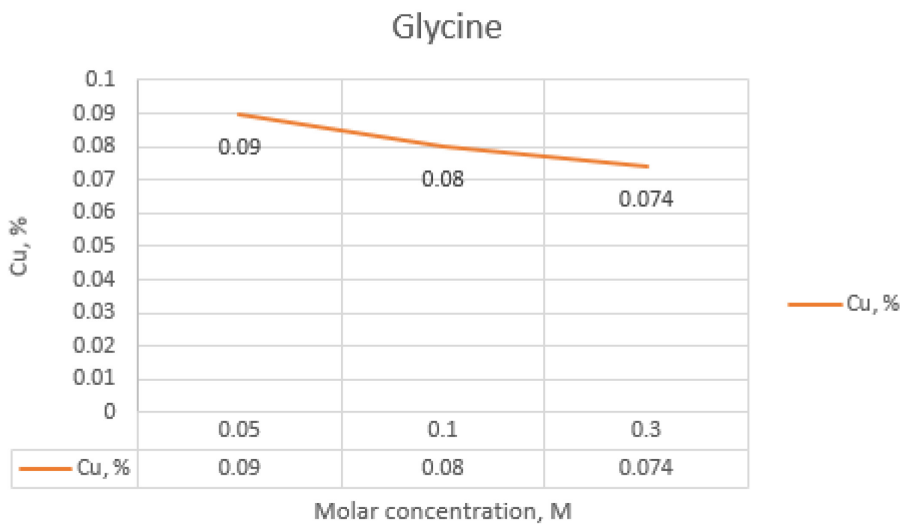


Figure 4. 2 XRF Analyzer Result of the Glycine Residue

The obtained results underscore the significance of calibration in ensuring the accuracy of both equipment and apparatus. Furthermore, external factors can considerably influence XRF outcomes, implying that results should be approached with caution. It is imperative to acknowledge the possibility of errors in the results, which could impact the overall reliability and validity of the findings. Therefore, it is recommended to take appropriate measures to address these limitations in future studies.

4.2 Leaching

The experimental procedure involves the utilization of two distinct types of reagents, each requiring different leaching conditions. Sulfuric acid, being an acidic solution, initiates the leaching process at a considerably lower pH level, whereas glycine necessitates an alkaline environment for effective copper leaching. Achieving the desired pH level of 10 for glycine leaching required a significant amount of sodium hydroxide, potentially exceeding that of the glycine itself. Therefore, considering this similar amount of pH adjustment, it was difficult to

increase the pH to the optimal amount. Consequently, it becomes challenging to differentiate whether the observed outcomes are solely attributable to the reagents or if the pH adjustments also play a significant role. The interplay between the reagents and pH adjustments introduces complexity to the experimental analysis, highlighting the need for careful interpretation and evaluation of the obtained results.

To ensure the optimal recovery of copper, various ancillary parameters come into play, including environmental temperature, stirring speed, and the use of an oxidizer. However, in this particular experiment, altering the environmental temperature posed certain challenges that could not be overcome due to limitations in modifying the existing infrastructure, such as the RMPL setup. Attempts to address this included options like placing a heater near the bottle roller or adding insulation to the surrounding area. Regrettably, these solutions proved infeasible. Consequently, it was decided to maintain a constant room temperature throughout the experiments. By doing so, the focus shifted to studying the specific effects of different reagents and their impact on varying concentrations, assuming that the stirring speed remained constant within each experimental setup.

4.2.1 Effect of reagent concentrations

The graph presented below depicts the results obtained from the sulfuric acid bottle roll experiment. A clear trend can be observed, wherein an increase in sulfuric acid concentration correlates with a higher quantity of dissolved copper ions in the solution. As the concentration of sulfuric acid rises, the amount of copper ions dissolved also tends to increase. However, it is worth noting that as the sulfuric acid concentration continues to increase, the difference in the amount of dissolved copper ions becomes less pronounced. This observation suggests that there may be a threshold beyond which further increments in

sulfuric acid concentration have a diminishing effect on the dissolution of copper ions.

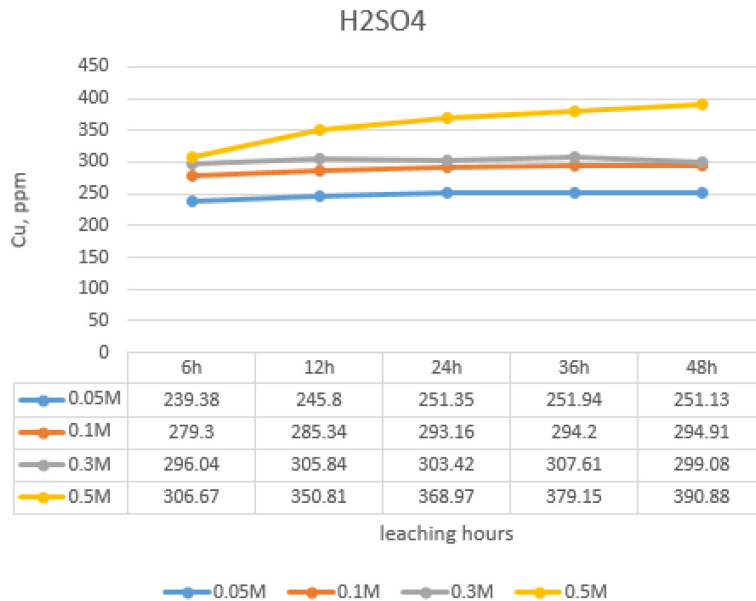


Figure 4. 3 Result of the Sulfuric acid Leaching Experiment in ppm

It is evident from the graph that a concentration of 0.5M sulfuric acid yields the highest performance in terms of copper ion dissolution. As the concentration of sulfuric acid increases, there is a corresponding increase in the amount of copper ions dissolved in the solution. This finding indicates that higher concentrations of sulfuric acid result in a more efficient leaching process and facilitate greater copper extraction. Therefore, it can be concluded that higher sulfuric acid concentrations are conducive to the enhanced dissolution of copper ions, emphasizing the significance of optimizing the acid concentration for maximizing copper recovery.

Contrary to the findings reported in the literature review, the experimental results depicted below demonstrate a direct relationship between glycine concentration and the number of dissolved copper ions. It is important to consider the potential influence of pH levels on the leaching process. The literature suggests that the optimal pH level for glycine leaching exceeds 10.5, whereas the experimental conditions in this study maintained a pH level of 10. This disparity in pH levels may have impacted the leaching process and contributed to the observed outcome. It is possible that the lower glycine concentration, combined with the suboptimal pH level, resulted in a deviation from the expected trend. These findings highlight the significance of maintaining the appropriate pH level and considering the interplay between reagent concentration and pH in glycine leaching experiments for effective copper extraction. Further investigation is warranted to elucidate the underlying mechanisms and

optimize the experimental conditions for enhanced copper dissolution.

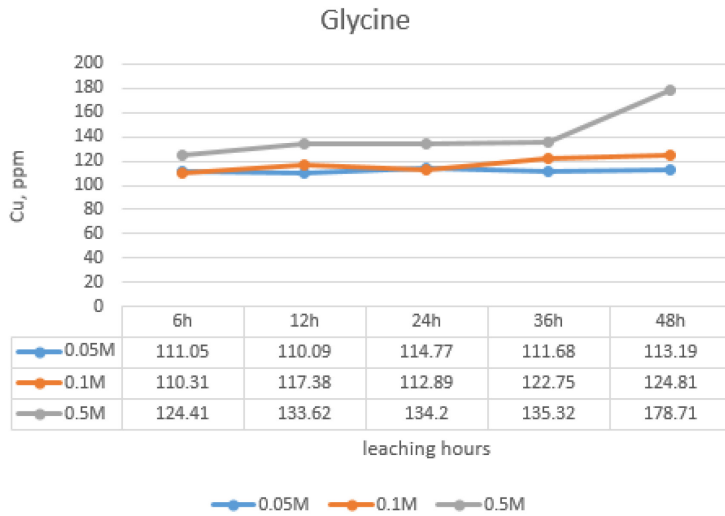


Figure 4. 4 Result of the glycine experiment

The presented graphs depict the impact of hydrogen peroxide on the quantity of dissolved copper ions. Hydrogen peroxide serves the purpose of enhancing the number of dissolved copper ions by facilitating the oxidation of copper sulfide ore. In the experiment without hydrogen peroxide, employing a constant glycine leaching concentration of 0.3M, the initial measurement of dissolved copper ions commenced at 88.99 ppm. Conversely, in the graph illustrating the experiment with a constant glycine leaching concentration of 0.3M, supplemented with hydrogen peroxide, the initial measurement of dissolved copper ions began at 93.9 ppm. These findings indicate that the inclusion of hydrogen peroxide as an additional chemical agent effectively oxidized the copper sulfide ore, leading to an increased quantity of dissolved copper ions.

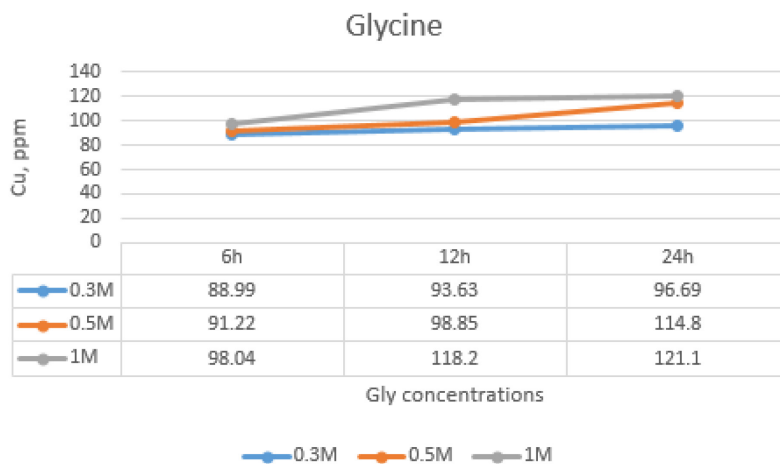


Figure 4. 5 Result of second Bottle Roll Experiment with Glycine

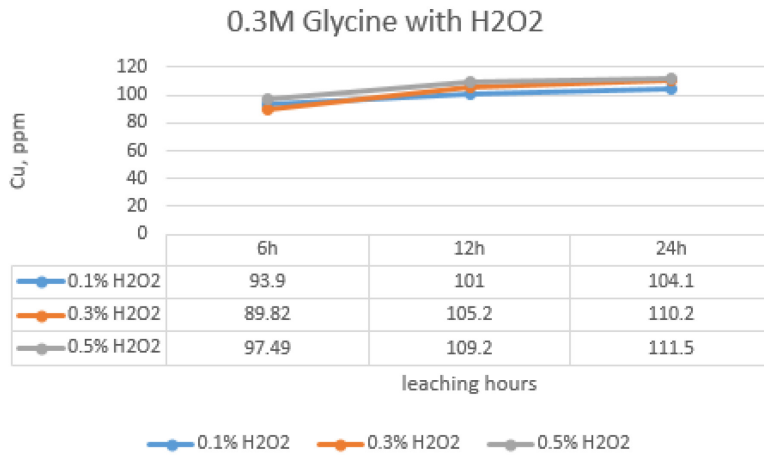


Figure 4. 6 Constant 0.3M concentration Glycine leaching with different percentage of H₂O₂ Experiment Result

4.2.2 Effect of reagents

The experimental findings from the thesis work revealed that sulfuric acid exhibited a higher effectiveness compared to glycine in terms of the dissolution of copper ions. Sulfuric acid demonstrated a notably larger number of dissolved copper ions, indicating its superior leaching capacity. On the other hand, while glycine also facilitated the dissolution of copper ions, the observed results indicated a lower level of copper ion dissolution compared to the anticipated outcome. The disparity between the number of dissolved copper ions in sulfuric acid and glycine was significant, with sulfuric acid exhibiting a substantially higher efficacy in this regard.

The utilization of hydrogen peroxide in glycine leaching proved to be effective in oxidizing the copper sulfide ore, as evidenced by the results presented in the preceding graph. However, it is important to note that the pH level plays a crucial role in optimizing the outcome of the glycine leaching process. To achieve significantly improved results, it is recommended to maintain the pH level within the optimal range of at least 10.5 during glycine leaching with hydrogen peroxide. This ensures a more favorable environment for the reaction, leading to a higher yield of dissolved copper ions and enhanced overall efficiency in the leaching process.

4.3 Discussion of optimum reagents for reprocessing tailing pond

Based on the experimental results, sulfuric acid emerged as the optimal reagent due to its ability to dissolve a higher number of copper ions. Sulfuric acid is widely recognized for its high leaching efficiency; however, its significant environmental impact poses a challenge. Proper treatment of sulfuric acid after the leaching process becomes a crucial concern. Consequently, it is imperative for modern society to explore alternatives and gradually phase out the use of sulfuric acid.

In contrast, glycine, a commercially available reagent, has gained recognition for its remarkable efficiency in the leaching process, particularly in gold extraction. Glycine has proven to be a viable substitute for cyanide, given its superior performance and lower toxicity compared to cyanide. The adoption of glycine as a leaching reagent not only enhances the efficiency of the process but also addresses the pressing environmental and safety concerns associated with traditional cyanide-based methods.

Therefore, transitioning towards the utilization of glycine and similar environmentally friendly reagents holds significant promise in achieving sustainable and responsible mining practices. By embracing these alternatives, we can mitigate the environmental impact of mining operations while maintaining high leaching efficiency and ensuring the safety of both workers and the surrounding ecosystem.

CONCLUSIONS:

The investigation presented above revealed some interesting findings regarding the effectiveness and practical considerations of reagents used in the leaching process. Glycine, being a promising commercial reagent, was initially chosen due to its higher effectiveness compared to traditional reagents like cyanide. Moreover, glycine exhibits lower toxicity, making it an attractive alternative. However, the experimental results demonstrated that sulfuric acid outperformed glycine in terms of copper dissolution, as evidenced by the aforementioned findings. This unexpected outcome highlights the complexity of real-life scenarios and the importance of empirical data to guide decision-making processes.

Another notable observation was the successful use of hydrogen peroxide for the oxidation of copper sulfide ore. This addition proved to be highly effective in enhancing the leaching process. However, an unforeseen issue arose during the experiment when the plastic bottle containing hydrogen peroxide experienced an explosion. This incident occurred due to the high percentage of hydrogen peroxide used and the closure of the bottle with its lid. It is crucial to exercise caution and consider measures to prevent high pressure when employing hydrogen peroxide or similar substances in a closed system to ensure the safety of the experiment.

Furthermore, the usage of sodium hydroxide for pH adjustment posed challenges due to the significant quantity required. This raised concerns about its potential impact on the experimental outcomes. As a result, the pH level was not adjusted to the desired higher value, which is known to be optimal for glycine leaching. The decision to maintain the pH level at 10 instead of the recommended level of at least 10.5 may have contributed to the lower number of copper ions dissolved in the glycine solution compared to sulfuric acid.

These findings underscore the importance of carefully considering practical aspects and potential limitations when selecting reagents and adjusting experimental parameters. The results provide valuable insights for future investigations and emphasize the need for further optimization and refinement of the leaching process to achieve desired outcomes efficiently and safely.

RECOMMENDATION:

Based on the findings of this study, there are several recommendations for future research on sulfuric acid and glycine leaching in the context of copper sulfide ore. Firstly, the utilization of hydrogen peroxide as an oxidizing agent has proven to be highly beneficial for enhancing the leaching process. However, it is crucial to address the safety concerns associated with potential explosions caused by high pressure. Therefore, it is recommended to exercise caution and avoid conducting experiments in closed containers or similar confined environments that may lead to pressure build-up. Alternatively, if a closed system is necessary, it is imperative to carefully regulate the percentage of hydrogen peroxide to mitigate the risk of pressure-related incidents.

Furthermore, it is advisable to explore alternative methods or apparatus configurations that can provide a controlled and safe environment for utilizing hydrogen peroxide in the leaching process. This may involve implementing specialized equipment or modifying experimental setups to ensure adequate pressure relief mechanisms and prevent hazardous situations.

In addition to the precautions related to hydrogen peroxide, it is essential to consider the specific requirements and characteristics of sulfuric acid and glycine leaching. Future studies should focus on optimizing the parameters such as reagent concentrations, pH levels, and reaction times to maximize the efficiency and effectiveness of both leaching methods. Moreover, a thorough investigation into the potential environmental impacts associated with the use of sulfuric acid should be conducted to develop appropriate mitigation strategies.

To advance the understanding of glycine leaching, further research should explore the reasons behind its lower performance compared to sulfuric acid in terms of copper ion dissolution. Investigating the influence of pH levels within the optimal range (above 10.5) and examining the interaction between glycine and copper sulfide ore could provide valuable insights for improving its leaching efficiency.

Lastly, future research should prioritize the safe implementation of hydrogen peroxide, optimize the parameters of sulfuric acid and glycine leaching, and delve into the mechanisms underlying the performance differences between these reagents. By addressing these aspects, researchers can contribute to the development of more effective and sustainable leaching techniques for copper sulfide ore processing.

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APPENDIX

APPENDIX 1 Elemental Analysis Result of the Experiment Residue

	Cu	Mg	Al	Bal	Si	P	S	K	Ca	Mn
Specimen	0.107	-	8.81	57.09	27.01	0.095	0.462	3.51	0.369	-
	0.110	-	9.04	57.20	27.18	0.115	0.465	3.49	0.376	-
H2SO4, 0.05 M	0.057	0.833	9.77	53.36	29.67	0.118	0.546	3.40	0.226	0.029
	0.056	1.41	9.61	53.80	28.91	0.127	0.552	3.34	0.204	0.017
H2SO4, 0.1 M	0.050	-	9.33	55.59	29.02	0.097	0.606	3.29	0.273	-
	0.049	1.14	8.74	57.08	27.07	0.088	0.580	3.30	0.256	-
H2SO4, 0.3 M	0.052	-	8.79	56.66	28.47	0.083	0.682	3.25	0.235	0.015
	0.050	0.821	9.38	54.46	29.15	0.076	0.719	3.33	0.229	-
H2SO4, 0.5 M	0.051	0.525	9.18	55.56	28.66	0.060	0.644	3.39	0.223	-
	0.052	-	8.17	58.22	27.61	0.050	0.612	3.36	0.220	0.015
Gly, 0.05 M	0.089	-	8.51	37.38	27.84	0.121	0.445	3.23	0.354	0.014
	0.091	1.01	9.42	54.78	28.51	0.110	0.473	3.27	0.328	0.016
Gly, 0.1 M	0.079	-	8.78	56.69	28.21	0.112	0.508	3.29	0.333	0.025
	0.081	0.043	8.93	55.80	28.36	0.130	0.480	3.24	0.346	0.019
Gly, 0.3 M	0.074	0.503	8.23	57.01	28.01	0.107	0.503	3.14	0.324	0.032
	0.074	0.522	8.87	55.17	29.27	0.116	0.492	3.15	0.361	0.022

	Fe	Zn	As	Rb	Sr	Zr	Nb	Ba	Pb	Mo
Specimen	1.86	0.008	0.004	0.008	0.033	0.010	0.015	0.067	0.003	0.008
	1.85	0.011	0.003	0.007	0.033	0.012	0.015	0.091	0.003	0.007
H2SO4, 0.05 M	1.80	0.010	0.003	0.008	0.033	0.014	0.017	0.086	0.003	0.009
	1.79	0.012	0.002	0.008	0.034	0.014	0.017	0.090	0.004	0.010
H2SO4, 0.1 M	1.57	0.010	0.003	0.008	0.032	0.011	0.011	0.077	0.002	0.006
	1.53	0.013	-	0.007	0.032	0.011	0.013	0.069	0.003	0.006
H2SO4, 0.3 M	1.59	0.011	0.002	0.006	0.033	0.013	0.016	0.082	0.003	0.006
	1.62	0.010	0.002	0.007	0.033	0.013	0.019	0.086	0.003	0.008
H2SO4, 0.5 M	1.48	0.016	-	0.007	0.034	0.013	0.015	0.084	0.004	0.008
	1.47	0.011	0.002	0.009	0.033	0.014	0.017	0.088	-	0.008
Gly, 0.05 M	1.84	0.010	-	0.007	0.034	0.014	0.016	0.084	0.005	0.010
	1.84	0.008	0.002	0.007	0.034	0.016	0.015	0.065	0.002	0.007
Gly, 0.1 M	1.82	0.006	0.003	0.008	0.033	0.013	0.014	0.077	0.003	0.007
	1.82	0.009	-	0.008	0.033	0.009	0.016	0.068	0.005	0.007
Gly, 0.3 M	1.87	0.012	0.002	0.007	0.035	0.011	0.017	0.097	0.004	0.008
	1.79	0.008	0.002	0.008	0.033	0.013	0.016	0.097	0.004	0.008

APPENDIX 2 Experiment Result of the Sulfuric acid leaching

Hour	H ₂ SO ₄ , 0.05 M			H ₂ SO ₄ , 0.1 M			H ₂ SO ₄ , 0.3 M			H ₂ SO ₄ , 0.5 M		
	pH	Cu, ppm	DO	pH	Cu, ppm	DO	pH	Cu, ppm	DO	pH	Cu, ppm	DO
6	2.2	239.38	6.22	1.5	279.3	6.22	0.8	296.04	6.29	0.7	306.67	6.3
12	2.6	245.8	5.99	1.7	285.34	6.2	1	305.84	6.14	0.8	350.81	6.2
24	2.8	251.35	6.15	1.6	293.16	6.41	1.1	303.42	6.38	0.8	368.97	6.34
36	3	251.94	5.03	1.7	294.2	6.13	1.1	307.61	6.37	0.8	379.15	6.29
48	3.1	251.13	6.33	1.7	294.91	6.18	1.3	299.08	6.32	1.1	390.88	6.42

APPENDIX 3 Experiment Result of the Glycine leaching

Hour	Gly 0.05 M			Gly 0.1 M			Gly 0.3 M		
	pH	DO	Cu, ppm	pH	DO	Cu, ppm	pH	DO	Cu, ppm
6	9.4	7.25	111.05	9.7	7.26	110.31	9.7	7.03	124.41
12	9.8	6.98	110.09	9.9	7.06	117.38	10	6.86	133.62
24	9.8	7.04	114.77	9.9	7.22	112.89	10.1	7.15	134.2
36	10	6.9	111.68	9.9	6.97	122.75	10	6.87	135.32
48	10		113.19	10		124.81	10		178.71

APPENDIX 4 Constant 0.3M concentration of Glycine with different percentage of Hydrogen Peroxide.

Percentage of H ₂ O ₂ (mol/L)	Amount of H ₂ O ₂ (ml)	0h		6h			12h			24h		
		pH	DO	pH	DO	Cu, ppm	pH	DO	Cu, ppm	pH	DO	Cu, ppm
Distilled water		6.33	5.83	7.8	6		6.01	6.37		5.3	6.08	
0.1	3.5	6.18	6.54	9.93	8.93	93.9	10	6.3	101	10	6.21	104.1
0.3	10.5	6.93	6.56	10.04	9.96	89.82	9.98	5.9	105.2	10.01	4.98	110.2
0.5	17.5	6.86	6.55	10.04	9.6	97.49	9.96	4.81	109.2	9.99	2.35	111.5

APPENDIX 5 Higher concentration of the Glycine leaching

Glycine, M	Glycine, g	0h		6h			12h			24h		
		pH	DO	pH	DO	Cu, ppm	pH	DO	Cu, ppm	pH	DO	Cu, ppm
Distilled water		5.42	6.12	6.63	6.2		6.75	6.32		5.2	6.43	
0.3	23.625	5.34	6.17	10.13	6.58	88.99	10.17	6.89	93.63	10.12	6.79	96.69
0.5	39.41	6.85	6.04	10.14	6.59	91.22	10.14	6.7	98.85	10.1	6.25	114.8
1	78.82	6.81	6	10.25	6.22	98.04	10.25	6.53	118.2			121.1